A TEXT-BOOK

ON

GAS, OIL, AND AIR ENGINES.

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GAS, OIL, AND AIR ENGINES;

OR,

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INTERNAL COMBUSTION MOTORS WITHOUT BOILER.

BY

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WITH 154 ILLUSTRATIONS AND SELECTED TABLE OF TRIALS.

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PREFACE TO THE SECOND EDITION.

DURING the last few years the increase in the number of gas and oil engines used for all kinds of industrial and home enterprises has been remarkable. Their number and power are growing every year, and these motors compete with steam engines, not only in England and America, where gas and oil are cheap, but also in Germany and Switzerland. In France, on the other hand, where both gas and oil are more expensive, they are not so much in request. Dowson or other cheap power gas is now widely used in all these countries for driving engines with one or more cylinders, up to 300 and 400 H.P. That both gas and oil engines now run with greater regularity than in the past is due to the fact that the governing arrangements are better.

Every year witnesses new applications of "internal combustion" motors to mills, production of electric light, tramways, hammers, cranes, road carriages, pumps for water, irrigation and sewage, and all varieties of agricultural purposes. The portability of small oil engines renders them most convenient for farm work, and for use in villages and other places where gas is not made. Nearly all these motors work with the four-cycle, and with lift valves. All the larger sizes are horizontal, with circulating water jackets for cooling the cylinder, &c. Gas engines are nearly always single acting and single cylinder, except

for the largest powers, when two cylinders are generally used. The charge is usually fired by tube ignition, sometimes by electricity. The piston speed is usually from 600 to 700 feet per minute. The clearance volumes are much larger than in steam engines, generally from 20 to 50 per cent. of the volume generated by the piston, and 3 to 8 per cent. in steam engines. The names which stand out most prominently as regards improvements, trials, and study of gases and the modern gas engine are:—Lenoir, Otto, Beau de Rochas, Clerk, Atkinson, Crossley, Delamare-Deboutteville, Slaby, Witz, Daimler, Capitaine, Dowson, Lencauchez, Schöttler, Mallard, Le Châtelier, Berthelot, and others; and for oil engines:—Brayton, Priestman, Daimler, Hornsby, Roots, and others.

One reason which may account for the great development of gas and oil motors, besides their convenience and absence of a boiler, is their much larger thermal efficiency, as compared with that of steam engines. The best modern compound or triple steam motors, using 120 to 150 lbs. steam pressure, working with about the same piston speed as gas engines, give from 10 to 15 per cent. heat efficiency; in other words, of the total heat given to the engine, some 12 per cent. only is converted into indicated work. With gas it is sometimes as much as 28 per cent.; more often, however, from 15 to 25 per cent. This is chiefly due to the higher temperatures of internal combustion engines, rather than to the greater number of expansions. Not only should the heat efficiency of such motors be well considered, but especially the actual cost of the heat units in a cubic foot of gas or pound of oil, in different localities. Gas, oil, and coal or coke are all different forms of fuel, gaseous, liquid, or solid, and contain so many thermal units, varying

largely in value in different towns. The steam engine has had a life of some 130 years, the gas engine only about 33 years, or say a quarter of the time, oil about 10 years, cheap or power gas about 15 years. As yet there are very few applications of gas and oil to marine engines, and no oil locomotives are working. On the other hand the number of small boats on rivers, lakes, and canals, worked by oil, gas, or gasolene motors, is very considerable, thousands being in use in Europe.

The number of exact and reliable trials on gas and oil motors is also decidedly on the increase. Independent tests, when well made, give valuable information, and generally lead to improvements by the makers, with whom, however, they are not popular. Some new and interesting experiments by Mr. Burstall, on the high temperatures inside gas engine cylinders at different parts of the stroke, should be read by those who desire to study this subject, and Herr Meyer's experiments at Zurich also deserve special notice.

The remarkable engineering and chemical fact to be duly appreciated is that tens of thousands of gas and oil engines are constantly working, under conditions which, at first sight, appear impossible—*i.e.*, with explosions and red-hot flames at every other revolution—and yet no difficulty is found in the cylinders with lubrication, valves, &c. The cylinder and piston must be kept sufficiently cool by the use of a water jacket, and mineral oil used for lubrication. If this be done no practical difficulty is experienced, although during explosion and combustion very high temperatures are attained. About one-third of the total heat produced is often carried off in the jacket-water, otherwise

the engine could not work at all. There is here a large opening for important future improvements.

The initial pressures in gas engines—as shown by the indicator diagrams—are constantly on the increase, due chiefly to the more complete expulsion of the products of combustion. In 1862 the initial pressure was only about 50 lbs., while in 1895 it reached 300 lbs. in the Crossley-Atkinson engine. We are thus approaching the "theoretically attainable," but this point is still far off.

No practical rotatory or "impulse" gas or oil motors, on the lines of the well-known Laval Steam Turbine, are yet in the market.

A chronological list of the development of Gas and Oil engines is given after this Preface.

With these preliminary remarks, we may pass on to say, briefly, that the present work is divided into three parts, treating respectively of Gas, Oil, and Air Engines. Part I., on Gas Engines, is divided into two sections, one dealing with the early history of these motors, and the other with modern commercial engines.

An Appendix is added in six sections, containing information that could not well be incorporated in the text. One of them gives an abstract of the valuable researches and experiments made by Dr. Slaby, of Berlin.

The theory of the gas engine is briefly discussed in several chapters, and in this part I have had the advantage of the valuable criticism of Professor Capper, of King's College, London, who has also kindly made, for publication in this work, a detailed test upon the experimental Otto-Crossley gas engine in his Engineering Laboratory.

Chapter XVII., on the "Chemical Composition of Gas,"

has been entrusted to Mr. G. N. Huntly, A.R.C.S., and he is responsible for this chapter only.

I am much indebted to numerous recognised authorities on the subject, especially to the excellent works of Professors Schöttler and Witz, Mr. Dugald Clerk, Professors Boulvin, Jenkin, and Robinson, Dr. Slaby, M. Chauveau, and others. Information has also been obtained from the *Proceedings of the Institution of Civil Engineers*, *Proceedings of the Institution of Mechanical Engineers*, *Comptes Rendus de la Société des Ingénieurs Civils*, *Zeitschrift des Vereines deutscher Ingenieure*, *The Engineer*, *Engineering*, *Journal of Gas Lighting*, and various other scientific and technical periodicals. A list is added of the literature of the subject both English and Foreign, which, it is hoped, will be found fairly complete.

In this Second Edition, care has also been taken to consult the best authorities in England and on the Continent, who have written on the theory and practice of Gas and Oil Engines and Gas Generators, and in every way to bring the matter up to date.

Finally, a list has been added of 140 selected tests and experiments on Gas, Oil, and Air Engines, published up to 1895.

BRYAN DONKIN.

BERMONDSEY, LONDON, *May*, 1896.

TABLE OF CONTENTS.

PART I.—GAS ENGINES.

CHAPTER I.—GENERAL DESCRIPTION OF THE ACTION AND PARTS OF A GAS ENGINE.

CHAPTER II.—HEAT CYCLES, AND CLASSIFICATION OF GAS ENGINES.

CHAPTER III.—HISTORY OF THE GAS ENGINE.

Chapter IV.—History of the Gas Engine—(*Continued*).

Chapter V.—History of the Gas Engine—(*Continued*).

Chapter VI.—History of the Gas Engine—(*Continued*).

Chapter VII.—The Otto Gas Engine, 1876.

CHAPTER XIII.—GERMAN GAS ENGINES—THE KOERTING, ADAM, AND BENZ.

CHAPTER XIV.—OTHER GERMAN GAS ENGINES.

CHAPTER XV.—GAS PRODUCTION FOR MOTIVE POWER.

CHAPTER XVI.—THE THEORY OF THE GAS ENGINE.

Chapter XVII.—The Chemical Composition of Gas in Gas Engines.

Chapter XVIII.—The Utilisation of Heat in a Gas Engine.

Chapter XIX.—Explosion and Combustion in a Gas Engine.

PART II.—PETROLEUM ENGINES.

Chapter XX.—The Discovery, Utilisation, and Properties of Oil.

Chapter XXI.—Historical—Working Method in Oil Engines—Carburetted Air.

Chapter XXII.—The Priestman Oil Engine and Yarrow Spirit Launch.

Chapter XXIII.—Other British Oil Engines.

Chapter XXIV.—American Gas and Oil Engines.

Chapter XXV.—French Oil Engines.

Chapter XXVI.—German Oil Engines.

CHAPTER XXVII.—PRACTICAL APPLICATIONS OF GAS AND OIL ENGINES.

PART III.

CHAPTER XXVIII.—AIR ENGINES.

APPENDIX.

DEVELOPMENT OF THE MODERN *GAS* ENGINE.

APPROXIMATE DATES.

	Year.
First horizontal Lenoir French engine, water jacketed, with slide valve (40 cubic feet of gas per I.H.P. hour). Electric ignition, .	1861
Hugon gas engine. First engine with ignition slide valve, . .	1863
Otto & Langen's atmospheric engine, ...	1866
Practically very few English makers of gas engines, perhaps one or two, ...	1870
Bisschop engine, made by Andrews, ...	1872
Robson, compression on one side of piston, and ignition on the other, ...	1877
First Clerk engine with air pump and compression, ...	1877
First horizontal Otto engine, Crossley (25 cubic feet gas per I.H.P. hour), ...	1879
Robson, first starter of compressed gas in a reservoir, . . .	1879
Firms making gas engines in England—Simon, Andrews, Tangye, Robson, and others, ...	1880
Dowson first gas producer, ...	1878-1880
Heat efficiency of the best engines, 10 to 15 per cent., . . .	1882
First porcelain tube ignition, Watson, ...	1881
Best heat efficiency of Otto engine (5 to 15 I.H.P.), 15 per cent. (taking indicated work), ...	1887
First Otto-Crossley without slide, ...	1888
Society of Arts' trials—Otto-Crossley engine, 22 per cent. heat efficiency (taking B.H.P.), ...	1888
First Daimler gas engine, ...	1889
First timing valve, Otto-Crossley engine over 100 B.H.P., . .	1889
Expiration of Otto patent in England, ...	1890
Maximum power, 200 to 300 I.H.P. engines in England, France, and Germany, ...	1890-1894
Approximate number of firms making gas engines—England 30, Germany 30, France 20, Switzerland 5, ...	
Power gas, $\frac{3}{4}$ lb. to 1 lb., good anthracite coal per B.H.P., 50 to 200 H.P., ...	
Heat efficiency, 16 per cent. to 26 per cent. in best engines (taking B.H.P.), ...	1895
Maximum initial pressure in cylinder about 200 lbs., ...	
Largest engines made about 300 to 400 I.H.P., ...	

DEVELOPMENT OF THE MODERN *OIL* ENGINE.

APPROXIMATE DATES.

	Year.
First oil engine exhibited at the Royal Agricultural Society's Show at Newcastle (Spiel's petroleum engine) by Shirlaw & Co., Nottingham, ...	1887
Messrs. Priestman first exhibited a 4 H.P. petroleum engine at the Nottingham Meeting of the Royal Agricultural Society, using ordinary lamp oil, ...	1888
One or two makers in England, ...	1888
A 6 H.P. portable oil engine exhibited at the Windsor Meeting of the Royal Agricultural Society, by Messrs. Priestman, . .	1889
Royal Agricultural Society, Plymouth Meeting. Light portable motors. Prize awarded to Messrs. Priestman for $4\frac{1}{2}$ H.P. portable, ...	1890
Royal Agricultural Society, Cambridge Meeting. Fixed engines, 4 to 8 B.H.P., 11 exhibited. Portable engines, 9 to 16 B.H.P., 6 exhibited. Prizes awarded to Messrs. Hornsby and Messrs. Crossley, ...	1894
Approximate number of firms making oil engines—Germany 30, England 20, France 10, Switzerland 5, ...	1895
Heat efficiency in the best engines, taking B.H.P. 10 per cent. to 20 per cent., ... }	1895
Largest engines made about 60 to 80 I.H.P., ... }	1895

LIST OF ILLUSTRATIONS.

A TEXT-BOOK OF

GAS, OIL, AND AIR ENGINES.

PART I.—GAS ENGINES.

CHAPTER I.

GENERAL DESCRIPTION OF THE ACTION AND PARTS OF A GAS ENGINE.

THE principles governing the construction and action of a gas motor are almost the same as those of a steam engine. In both the object is to obtain useful work from heat. This is effected by raising gas or water to a certain temperature, producing in the one case steam, in the other flame, and with the pressures resulting from the increase of heat in the steam or flame driving forward a piston connected to a shaft. The science of thermodynamics proves that there exists a strict ratio between the heat evolved and the work performed. The laws governing the production of this heat energy are always the same, whatever the medium or agent of motive force.

In mechanical motors there are three points to be considered:—1st. The cause of motion, varying according to the type of motor. In thermal engines it is heat obtained from the combustion of coal in a boiler or air furnace, or by the explosion of inflammable gases. 2nd. The effect produced, or the energy into which the heat is transformed; this usually takes the form of pressure upon a piston working on to a crank. So far, all heat motors are alike. 3rd. The particular mechanism, differing in each kind of motor, by which this translation of heat into work is utilised. The difference between steam and other kinds of motors, such as gas,

air, petroleum, &c., lies in the means employed to generate the heat, and turn it into work.

A steam motor consists of three indispensable parts, the furnace, the boiler, and the cylinder containing the motor piston. These may be in close proximity to each other, but there is usually a separate building for the boiler, &c. The process of starting a steam engine is relatively slow and laborious. The fire must be kindled and combustion obtained in the furnace, and the water in the boiler brought to boiling point and evaporated into steam. The temperature must then be raised until the pressure of the steam, produced by the increase of temperature, is sufficient to propel the motor piston.

Advantages of a Gas Engine.—In a gas engine these operations are much simpler, because it is so constructed that, for the work it has to perform, it is complete in itself, containing on one foundation the equivalent of furnace, boiler, and cylinder. It is in the cylinder that the production and utilisation of the heat takes place, and the entire cycle, or series of operations, is completely carried out. Highly inflammable gases and air are first admitted into the cylinder. They are, at a given moment, exploded by the application of heat or flame; the pressure and the temperature are at once considerably raised, and the piston is driven forward. In a steam engine the working agent is produced separately and continuously, but in a gas motor the explosive charge, which acts as the medium of heat, must be formed afresh at each stroke of the piston. With gas there is very little difficulty in obtaining an explosion, and a corresponding backward and forward stroke, as many times in a minute as is required. As combustion takes place in the cylinder itself, pressures and temperatures much greater than those developed in steam engines are easily and quickly produced. Gas motors are called "internal combustion" engines, and the same name is used for all motors in which the heat is generated inside, instead of outside, the cylinder.

This brief outline of the working of a gas motor shows the advantages it possesses in practice over the steam engine—namely, compactness and facility in starting. Theoretically, it is also superior, because higher initial temperatures are available, to act upon the piston. But in all heat motors hitherto made, there are defects which the skill of the best constructors has not yet been able to overcome—namely, waste of the greater part of the heat generated, and consequent loss of pressure, or of useful work done upon the piston.

Considering, first, the practical advantages of the gas engine, as far as compactness is concerned, it leaves little to be desired. The space it occupies is small, a few square feet being sufficient, instead of the separate boiler and chimney necessary with a steam engine. A gas motor can be fixed almost anywhere, but

it should stand on a solid foundation, to counteract the vibrations caused by the repeated explosions. To place it in proper working condition, all that is required is a gas supply pipe, and a water tank with pipes for cooling the cylinder. The high temperatures produced by the explosion of the gases necessitate the use of a jacket round the cylinder, through which water circulating automatically from a tank passes continuously, to keep it cool; this jacket water is used over and over again. These pipes, with a third communicating with the outer air, and providing an outlet for the burnt gases, constitute all the necessary working connections.

A gas engine thus easily fixed, can also be set in motion and started in a few minutes. If a gas jet or hot ignition tube is used to fire the charge, the gas is previously lighted; where combustion is obtained electrically, the generation of the sparks is produced before the engine is started. A few turns by hand or other means are given to the flywheel, while the exhaust is kept open, and the engine is then fairly at work. To stop it, nothing is needed but to turn off the supply of gas. For small manufactures the convenience of having a motive power at hand, easy to start or stop in a few moments, is so great, that small gas motors are rapidly superseding, not only steam, but manual labour. It cannot be denied that they are rather more costly than steam, but of late years their consumption of gas per H.P. has been much reduced. In proportion as the quantity of gas required to drive them is diminished, and the economy obtained is greater, the more popular and cheaper will they become. Practically, there is less danger of fire than with steam boilers, and thousands of gas engines are now used in places where steam could never be employed.

It is in the smaller gas engines that these practical advantages are chiefly felt, but the theoretical superiority of these motors, obtained by the high temperatures at which they can be worked, apply equally to engines of all sizes. But as soon as large powers are required, and the gas engine enters into active competition with steam, it becomes of far greater importance to economise the consumption of gas. The temperatures and pressures obtained by the inflammation and explosion of gas in a cylinder are so high, that engineers have not yet succeeded in utilising them to their full extent. Hence, there is much waste of heat and consequent loss of pressure, and these defects in the working of a gas engine affect injuriously the expenditure of gas. If heat be wasted, more must be supplied, and more gas must be used to produce it.

Waste of Heat.—In a steam engine the main object should be to keep the cylinder walls as hot as possible, to prevent the condensation of the steam. The difficulty of generating steam, and maintaining its temperature and pressure, is in-

creased, because there is a change of physical state from a liquid to steam. With a gas engine the reverse process is necessary, and the cylinder walls must be cooled. The gas is dry, and the heat developed by the explosions taking place in the cylinder acts directly on the piston. A considerable amount of steam is condensed in the pipes of a steam engine, whereas in a gas motor there is no similar waste, because all the heat is generated in the cylinder itself. Nevertheless heat is lost, but in a different way. The temperature of the gas at the moment of explosion is relatively high. It is generally about 2,730° F. (1,500° C.), but this is not the highest temperature reached. Whatever the actual temperature, the heat is always too great to be retained; a large portion is sacrificed, to prevent injury and destruction to the parts, and heat is also carried off continuously by the cooling water round the cylinder. In the early double-acting engines, not more than 4 to 6 per cent. of the total heat received was employed in doing work, and more than half was wasted, that the walls might be kept cool. If to this be added the heat escaping from the cylinder in the exhaust gases, or the products of combustion, it is not difficult to understand how, formerly, from 94 to 96 per cent. of the heat was dissipated.

It is this waste of heat in a gas motor that causes the loss of pressure, or diminution in the work done on the piston. With all gases the pressure increases with the rise in temperature, and, therefore, the higher the temperature, the greater will be the pressure produced, or the expansion of the gases. If this pressure be expended in doing work, and acting on the piston, the whole may, if expansion be continued long enough, be utilised in useful work. But to obtain this result with the pressures generated in a gas engine, the cylinder and piston must be of a certain length, and the piston allowed to move out as long as there is any expansive force left in the gas to act upon it. As this is practically impossible, the other plan is to diminish the quantity of gas admitted into the cylinder. Before compression was employed, it was difficult to proportion the supply of gas to the expansion, and it is a delicate process even in a modern engine, in which the gases are compressed before explosion.

When the theory of the gas engine began to be really understood, the principal problem was, how to obtain sufficient expansion from the exploded gases. The test of efficiency in any heat engine is the proportion between the total heat supplied, and the total useful work obtained. As far as work is concerned, all the heat which is not employed in producing it is wasted. Thus to be really efficient, a gas engine ought to furnish a maximum amount of useful work with a minimum consumption of gas. This is only possible if the expansion of the gases is

rapid and prolonged. The greater the time allowed them to act upon the piston, and the farther they drive it, the more heat energy will be expended in work, and the less will be discharged as waste into the atmosphere. Expansion should also be rapid, because the more quickly the piston uncovers successive portions of the cylinder walls, the less time will there be for useful heat to be carried off from the hot gases to the cooler walls. This important question of expansion will be more fully examined, when considering the theory and utilisation of heat in a gas engine.

The study of a gas engine falls naturally into two divisions :—

I. The source of power, or motive force.
II. Its mechanical utilisation.

I. Source of Power.—In all heat engines the source of power is heat, and gas is the medium or agent through which it acts in a gas motor. The gas is ignited, and the explosive force thus generated is used to drive forward a piston. Many different kinds of gas, varying in heating value, are employed, and the effects obtained by ignition and explosion cannot be determined without a knowledge of the chemical constituents of the gas, and the proportions in which they combine with the oxygen of the air. Since the gas used in an engine cylinder does not contain the oxygen necessary for combustion, it can never be burnt by itself, but must always be diluted with a certain quantity of air. Unless the composition of the gas and the ratio of its dilution with air are known, it is impossible to ascertain the temperatures and pressures attained in the cylinder, and to calculate the theoretical work, or the work it ought to do. The study of gases has led to the discovery of the law of dissociation, or the property they possess, after they have attained a certain high temperature, of resolving into their separate elements. The phenomena of ignition in a cylinder also prove that the whole heat of the gases is never developed at once, whatever the gas used, or the proportions in which it is diluted with air. It appears probable that combustion is seldom complete and instantaneous, but continues during the forward motion of the piston, after the first propagation of heat which causes the explosion. These and other questions connected with the phenomena of combustion in a gas engine are only mentioned here, and will be discussed later.

II. Utilisation of the Explosive Force, &c.—In the second part of the subject we have to consider the mechanical utilisation of the motive force, or the method by which it is turned into rotatory motion. This includes a study of the construction and parts of a gas engine, as the apparatus used for the transformation of heat into useful power. There is this peculiarity in its structure, that the cylinder contains in itself

furnace and boiler, and in it the motive power is developed. Before examining in detail the various types, it will be well to explain the principal parts of a gas motor, and its internal organisation. We will first enumerate these parts, and then describe the functions they have to perform, as also the different operations taking place in a gas engine.

Base.—The base plate on which the engine is fixed and the cylinder bolted is of cast iron, and usually very solid. In oil engines the interior of the base plate is often utilised as a reservoir for oil or air.

Cylinder.—The cylinder, solidly bolted to the base, is either vertical or horizontal, according to the type of motor. Few gas engines have more than one motor cylinder, working single acting; it is almost always open to the atmosphere at the crank end, and closed only by the piston. Except for large sizes a second cylinder is seldom needed to increase the motive power, sufficient force being obtained by the succession of explosions in one cylinder. With higher powers two or more single-acting cylinders are usually employed. As the great object in a gas engine is to allow the gases to expand as completely as possible, it seems at first as though this end would be best attained by making the engines compound, like steam engines, and causing the gases to expand successively in different cylinders. Though often tried, this arrangement has rarely been found successful. Sometimes an auxiliary pump is used for compressing the mixture, or a charging cylinder for receiving and mixing the gas and air. Occasionally compression is obtained in the motor cylinder itself, and the motor piston acts on one side as a pump. A special feature of gas engine cylinders is that, on account of the great heat developed, they are always provided with some apparatus for cooling the walls. In the smallest types it has been found sufficient to make the outer radiating surfaces of the cylinder ribbed or deeply indented, exposing a large cooling area to the air. In engines developing above two or three horse-power, a jacket with water constantly circulating through it is indispensable. As one end of the cylinder is almost always open to the air, the cylinder metal is kept cooler, and overheating is diminished by contact with the outer air, but chiefly by the water jacket.

Pistons.—The pistons of gas motors are very similar to those of steam engines, but longer. One or two types have valves in the pistons, to admit air or discharge the exhaust gases. Plunger pistons are generally used.

Valves.—The valves of a gas engine perform functions different to, but not less important than, the admission and exhaust valves of a steam engine. Not only do they admit the gases into the cylinder and discharge the products of combustion, but they are

frequently used to assist in mixing and firing the gas and air. In the older types of engine, as in the early Otto, there is generally one slide valve for admitting, mixing, and igniting the charge. It contains ports to receive and pass on the gas and air to the cylinder, and carries a lighted flame within a cavity to kindle the charge, after it is mixed and compressed. In most modern engines lift valves alone are used, but occasionally the mixture is admitted to the cylinder through cylindrical or piston valves, or a revolving disc. In many engines the valves are worked by cams on a side shaft driven from the main shaft, or by eccentrics; in others they are automatically lifted or closed by the pressures in the cylinder.

Transmission of Energy.—As in a steam engine, the pressure of explosion is generally transmitted direct from the connecting-rod to the revolving crank shaft. Occasionally there is no connecting-rod, the piston-rod working direct on to the shaft. To obtain greater regularity in the action of the engine, the flywheel is usually made larger and heavier than in steam engines. Most gas engines have only one explosion per two revolutions, and the energy of the flywheel is required to carry the piston forward, take in a fresh charge of gas and air, and to bring it back to the dead point after explosion.

In all gas engines five operations are required for a complete cycle—I. Admission and mixture of the charge of gas and air. II. Ignition. III. Explosion. IV. Expansion. V. Exhaust, or the discharge of the gases and products of combustion. To these has been added in most modern engines a sixth, namely, VI. Compression.* This cycle of work corresponds to each explosion, but not necessarily to each revolution; indeed, in many engines the number of revolutions and of explosions are independent of each other. The nature of these operations is as follows:—

I. Admission of the Gas and Air to the Cylinder.—This was formerly supposed to be a complicated process, and great care was taken to provide separate valves for admitting the air, and conducting the charge to the cylinder. Experience has shown that the air enters freely through any aperture, which is usually placed in proximity to the gas admission valve. Gas, unless made specially on the spot, is admitted through a pipe from any ordinary gas main. In the older engines, admission of the charge is made through a slide valve, as already described, moving to and fro between the slide cover and the cylinder. The gas pipe communicates with a passage in the slide cover, and a hole in the slide valve leading to a cavity. As soon as the cavity is filled with gas, the movement of the slide brings it opposite a similar opening in the cylinder, through which the gas

* In some engines part of a stroke is devoted to cleansing the cylinder of the burnt products.

enters. In later engines admission is effected through ordinary lift valves. Before entering the cylinder, the gas usually passes through a chamber where it is thoroughly mixed with its proper proportion of air, admitted through a separate inlet. Much importance was attached to this process of mixing before the use of compression, and different methods were resorted to, either to mix the gas and air, or to keep them in separate layers, and stratify them as they entered the cylinder. It is now almost universally admitted that these arrangements do not influence the explosion, and that stratification does not take place in the manner supposed, owing to the compressive force exerted by the piston. The gas admission valve is usually connected to the governor, which regulates the quantity of gas entering, and consequently the number or strength of the explosions.

II. Ignition.—The gases being admitted into the cylinder, the next operation is to fire or ignite them. This is usually a delicate process, because the return stroke of the piston exerts a considerable pressure upon the incoming charge, which may blow out the flame. The difficulty is increased in modern engines by the previous compression of the gas and air. Three methods of ignition are employed. 1. The electric spark. 2. A gas jet constantly burning. 3. A tube maintained at a red heat by a gas burner. Electricity was the first means proposed and adopted for igniting the gases, and it is still largely used in French engines. A current of electricity passes along wires placed close to the valve or chamber admitting the charge of gas and air, sparks are continually formed and fire the mixture. As the electric spark is sometimes found to be precarious in action, missing fire, and the charge is not ignited, an electric hammer is used to obtain a continuous stream of sparks. With flame ignition the charge, after being admitted into the slide valve and mixed, is, in compression engines, carried past a flame burning in a hollow of the valve. When the mixture is ignited the pressure of the burning gas often puts out the flame, and it is then relighted by an external permanent burner. The slide valve is held against the back of the cylinder, and is worked by an eccentric, but more often by a cam on the auxiliary or counter shaft driven from the main shaft. In England the most general method of ignition is, at present, by a hot tube. At a given moment the opening to this tube is uncovered, a portion of the charge at high pressure is brought in contact with it and fired, and explodes the remainder in the cylinder. The tube is kept at a red heat by a gas burner, and is easily replaced from time to time when it is worn out. Formerly these tubes were made of iron, and were "short-lived" as it is termed; very small tubes of platinum and other metals are sometimes used, which last much longer.*

* Porcelain tubes are also largely employed, but are scarcely suitable for oil engines, as they are apt to crack.

In some of the older types of engines, where the charge is admitted at atmospheric pressure, the gas and air are drawn in at one end of the cylinder by the suction of the forward stroke of the piston. At a certain moment a small flap valve covering a flame burning on the outside of the cylinder is lifted by the pressure, the flame drawn forward, and the mixture thus ignited. Sometimes the piston itself, in its out stroke, is used to uncover the gas and air valves. In other engines the gases are ignited in a separate chamber; there is no explosion, but they enter the cylinder in a state of flame, and force the piston forward.

III. and IV. Explosion and Expansion.—It is in the motor cylinder that explosion and expansion of the ignited gases almost always take place. To allow room for the compression and ignition of the charge, the clearance space is usually much larger than in steam engines, sometimes so large that it forms a separate chamber, into which the gas mixture is compressed. In the earlier types of gas motors, the charge was drawn in during the first part of the forward stroke, explosion taking place only when the piston had almost reached the middle of the cylinder. It was soon found that this tardy explosion greatly limited the number of expansions, and the work performed by the gases on the piston. Later engines were designed to procure the explosion as near the beginning of the stroke as possible, so as to allow the maximum volume of the cylinder for the expansion of the gases. In some vertical non-compression engines the clearance space is exceedingly small. Explosion of the gases takes place when the piston is at the bottom of its stroke, free of the crank and shaft, and drives it to the top of the cylinder.

V. Exhaust, or discharge of the gases.—Various methods are employed in gas engines for getting rid of the products of combustion, but the best authorities are now agreed that they should be expelled from the cylinder as quickly and as completely as possible. Most modern gas motors being single acting, or acting on one side of the piston only, the exhaust valve is seldom opened during the forward stroke. In some engines it only opens during half the return stroke, in others the whole of this stroke is utilised to expel the previous charge, while in a few engines a complete stroke, forward and return, is sacrificed to discharge the products of combustion, and cleanse the cylinder. Air under pressure is admitted to help the discharge in some modern engines. The exhaust valve plays an important part in a gas engine, because the high pressure in the cylinder is, of course, instantly reduced as soon as it is opened. Most gas engines are so constructed that the unburnt gases are allowed to escape at a relatively high pressure and temperature, which are thus wasted instead of being utilised. This is one of the defects of these motors which engineers should

be most anxious to remedy. In some vertical engines the piston is forced up by the explosion and driven down by atmospheric pressure, a partial vacuum being formed below by the cooling of the gases. The opening of the exhaust valve at the bottom of the cylinder, by causing the air to enter, equalises the pressure above and below the piston, and checks its descent. In the earlier engines the exhaust was usually connected to the admission and ignition valves, and one slide valve was made, during its motion to and fro, to uncover the three different openings. In others, and generally in the modern horizontal engines, the exhaust is under the cylinder, distinct from the admission valves, but worked from the same side shaft.

VI. Compression of the charge.—The sixth operation in a gas engine is the compression of the gas and air before ignition. This is the most important modern improvement introduced into these motors. As compared with the other operations, compression has certainly great influence on the consumption of gas, and on the economical working of the engine. It is effected in the following way :—A certain quantity of gas and air, in definite proportions, are admitted into the cylinder. Instead of being immediately ignited the mixture is compressed, and its pressure raised—that is, the volume of gas and air is forced into a much smaller space than before, by the return stroke of the motor piston. If, for example, the charge occupied a space of 5 cubic feet, it is driven back by the piston till it occupies only, say, 1 cubic foot, or one-fifth the previous space, and the pressure is raised five fold. The method usually adopted is to allow the piston to move out, and take in gas and air behind it till the whole cylinder is filled; the piston then returns, all the valves and ports being closed, and the mixture is driven into the clearance space and compressed. The advantages of this process are, that the particles of gas and air are forced much more closely together, and when they are ignited, their power of expansion has been found by experiment to be much greater. Nor do they part with their heat so quickly, being confined in a smaller space. Writers on the gas engine are unanimously of opinion that compression, previous to ignition, is the one great source of economy in gas motors, and this is confirmed by experiments. In the older non-compressing gas engines, it was always difficult to raise the pressure of the gases high enough to obtain much work on the piston. In modern compression engines, on the contrary, the expansive force of the gases is greater than can be properly utilised.

The advantages of compression are—(1) *The smaller size of cylinder required.* In the early engines, to obtain an effective working pressure, the cylinders were made large, and as much gas and air as possible admitted at a time, and even then the

pressure was often very low. But with engines using compression, since the same charge occupies a smaller space, the cylinder can be made smaller. (2) *Greater certainty and rapidity of explosion*, because the particles of gas, being forced closer together, and their temperature raised by compression, ignition proceeds more rapidly, and a more vigorous explosion is obtained. The flame is easily and surely transmitted, permeates the whole mass almost instantaneously, and the entire force of the explosion is developed. (3) *Greater economy of gas*, because, inflammation being certain, a poorer quality of gas can be used. Not only may the quantity be smaller in proportion to air, but the weaker charge, if compressed, will still explode, even when further diluted with the products of former combustion. (4) *A smaller cylinder is required for the same power*. (See Chapters xviii. and xix., where this subject is fully treated.)

Compression is carried out in two ways. If the engine has only one cylinder, it takes place in the motor cylinder itself, and a complete stroke, to and fro, is generally sacrificed to obtain it. If a pump is added, the charge is compressed in it; every stroke of the motor piston is then a working stroke, and the flywheel obtains an impulse at every revolution. The pump is worked from the crank shaft, and the six operations are divided between the two cylinders. The pump piston admits and compresses the charge, which is then exploded and expanded, and the products of combustion driven out from the motor cylinder. The two pistons work more or less simultaneously, and the forward stroke of the pump draws in the fresh mixture, during expansion of the charge in the motor cylinder. In other engines the pump is worked from a separate crank, set slightly in advance of the main crank. This cycle of operations is good, but its advantages are counterbalanced by the additional power required to drive the pump. Occasionally the gas and air are compressed into a separate receiver, and in a few engines the front part of the motor piston takes the place of the pump, and compresses the charge.

Oiling, &c.—Lubrication, starting, and regulation of the speed in a gas engine, each require a few words of explanation. Oiling the piston is a matter of much importance, and must be carefully performed. The high speeds and temperatures at which gas motors work necessitate a continuous and skilful use of good mineral oil. In steam engines there is generally a certain amount of water, but the flames of a gas engine dry the internal surfaces, and unless oil is continuously applied, the cylinder soon becomes hot and begins to suffer. Hence the importance of internal lubrication in all gas engines. They are usually fitted with a special apparatus for oiling the various parts automatically.

Small gas engines can be quickly started, but with large powers the process is not always easy. The engine should be at work in a few minutes, and the inertia of the working parts has to be overcome. All the larger motors are provided with special means of starting, such as a receiver, into which a reserve charge of gas and air is compressed, or a handle or cam acting upon the exhaust valve to keep it open, thus reducing the pressure in the cylinder. Sometimes a small auxiliary gas engine is used. MM. Delamare-Deboutteville and Malandin claim to have introduced an entirely new system, first shown in their Simplex engine at the Paris Exhibition of 1889. Other devices for starting have lately been patented.

Regulation of Speed.—To regulate the speed of an engine is rather a complicated process, and is effected in a variety of ways. Many different kinds of governors are used, though the majority are constructed on the principle of a weight acting by centrifugal force. A common type is the ball governor, but pendulum and air governors are also employed, while many governors are made with weighted arms or levers. The governor is generally in connection with the gas admission valve, but sometimes with the exhaust valve. The following are the usual methods of governing :—

1. By regulating the opening, more or less, of the gas admission valve.
2. By completely cutting off the supply of gas during a certain number of strokes.
3. By admitting more or less of the explosive charge at a time.
4. By acting on the exhaust valve and holding it open.

Sometimes two or more methods are used with the same engine, according to the greater or less fluctuations in the speed. To vary the quantity of gas within certain limits is an effectual check. But if a smaller quantity be admitted than will ignite when mixed with air, a certain amount of unburned gas passes through the cylinder, and into the exhaust. The speed is reduced because there is no explosion, but the gas is wasted. To reduce the total amount of the charge admitted may have a similar result, and give a weak stroke. In some modern engines the governor acts upon the gas valve to cut off the supply entirely for a time, when the speed is too high, Air alone being admitted, there is no explosion.

The tendency in modern gas motors is to simplify construction, and reduce the number of parts. Where only two lift valves are employed, one for admission, the other for discharge of the gases, the governor is usually connected to the exhaust. Under normal conditions of speed the suction of the forward stroke lifts the admission valve, and allows the charge to

enter. This valve closes as soon as compression begins, during the return stroke, and remains closed as long as the pressure in the cylinder is greater than that of the atmosphere. The opening of the exhaust valve reduces this pressure, and when the gases are all discharged the automatic admission valve rises, and a fresh charge is admitted. If the speed be too great the governor acts upon the exhaust valve, keeping it open. As no vacuum is formed in the cylinder during the return stroke, the admission valve remains closed, and no fresh charge can enter until the governor has released the exhaust. In oil engines, in which the charge is usually admitted through an automatic lift valve, the action of the governor on the exhaust is generally sufficient to prevent any fresh mixture reaching the cylinder.

CHAPTER II.

HEAT "CYCLES" AND CLASSIFICATION OF GAS ENGINES.

CONTENTS.—Theoretical Cycle—Heat Efficiency—Classification of Gas Engines by Types.

Theoretical Cycle.—The word "cycle," derived from the Greek, has the same signification as circle. As applied to mechanical motors it denotes a series of operations, at the end of which the working agent returns to its original condition, as at starting. The celebrated French engineer, Sadi Carnot, was the first to use the word in this sense, and for convenience it has been retained. Engineers have agreed to designate as a "cycle" the successive operations taking place in a heat motor, though these can never form what is termed a perfect or closed cycle. In every heat motor the same phenomena are repeated each time the gas, steam, or other working agent is introduced into the cylinder. In this sense, therefore, a given cycle of operations is periodically performed in these engines. The heat generated passes into the engine cylinder to perform the work. That portion of heat which has not been utilised in the engine is transferred to a source of cold, and the difference between these two sources (of heat and of cold) represents theoretically the heat expended in

work. A working agent is necessary, to which the heat must be imparted, and from which it is withdrawn.

The theoretical cycle imagined by Carnot, and called after him, was a perfect cycle, that is, the heat generated was employed solely in doing work, and none was wasted. The medium or "power agent," steam, gas, &c., was expanded, a piston was propelled, a given amount of work performed, and a given quantity of heat transformed into energy to produce this work. As the piston returned, it compressed the agent, restoring by compression all the heat that had been expended in work. A perfect cycle was realised, since the whole heat was thus returned to its source, and the working agent to its original condition. In practice a perfect cycle is impossible. Whatever the agent employed, it can never really return to its original condition, and all the heat be refunded, because a considerable quantity is irrecoverably lost. Much heat will escape through the cylinder walls; some will be wasted owing to imperfect expansion, passing out into the exhaust, and some will be expended in the friction of the engine. The more nearly, however, an engine approximates to the condition of a perfect cycle, and the more heat is expended in work on the piston, the greater will be the efficiency of the engine, and the higher the proportion between the useful work performed, and the heat received.

Heat Efficiency.—It has been shown that the higher the temperature of the mixture of gas and air in the cylinder produced by combustion, the greater the pressure, and, therefore, the greater should be the force exerted on the piston. On the other hand, the lower the temperature of the discharged gases, the more heat will be expended theoretically in work. The heat efficiency is the ratio of heat turned into work to the total heat received by the engine. In practice this efficiency is always diminished by waste of heat through various circumstances. Nevertheless, it is necessary to expand the gases as much as possible, because it is only by complete expansion that all the available heat can be utilised in doing work. If the gases are compressed by the return stroke of the piston, this heat will, theoretically, be refunded. Such a cycle of operations can, of course, be only obtained in theory, but in any case the more complete the expansion, the more the temperature and pressure of the gases discharged into the exhaust will be reduced. Less heat will be carried over from the cylinder, and more will remain to be utilised in it. Hence it is of the utmost importance to obtain as perfect a working cycle in a gas engine as possible.

Types of Engines.—Different authors have adopted different methods of classifying the various types of gas engines. An obvious, but not very satisfactory, way is to divide them into

horizontal and vertical. As a rule, engines for large powers are horizontal, and for small powers vertical; but in England almost all sizes are made horizontal. There is said to be less vibration than in vertical engines, and greater power is obtained for a cylinder of the same size, but many foreign makers are of opinion that the advantages of vertical engines outweigh their defects.

A more logical classification of gas motors, based on their internal working, is to divide them into engines drawing in the charge of gas and air at atmospheric pressure, and engines compressing the charge before ignition. This is the classification employed by the best authorities, and here adopted. In this way we get—

Type { I. Non-compressing engines; and
II. Compressing engines.

Each of these types may be subdivided into Classes *a* and *b*.

Type I., *Class a*, includes non-compressing motors drawing in and igniting the charge at atmospheric pressure. The force of the explosion drives the piston forward, and the return stroke expels the products of combustion. This type of engine is also made double-acting, giving an explosion or motor impulse per stroke on each side of the piston, and all the operations of admission, ignition, and expansion are effected while the piston moves once out and back again. The gases are discharged at the end of the stroke. These double-acting engines are not much used; the original Lenoir is the best example of the type.

Type I., *Class b*, also represents engines, chiefly vertical, which draw in and ignite the charge at atmospheric pressure. The piston is forced up from the bottom of the cylinder, and performs no work, not being connected to the crank. In the return stroke it is locked to the crank shaft, and descends only by the force of atmospheric pressure. This is the motor or working stroke. In a certain sense this class of engine is also double-acting, like Class *a*, the piston receiving two impulses per revolution; the first from the explosion of the gas below, the second from the pressure of the atmosphere above. The best representative of this type is the Otto and Langen engine. In one variety, the Bisschop, the piston is driven up with great force, but is permanently connected to the motor shaft, instead of being free during its ascent.

Type II. comprises all engines using compression, and like the first type is divided into two classes. *In Class a* the whole cycle of work, including compression, takes place in the motor cylinder itself, and in order to effect the various operations in one cylinder, it is necessary to sacrifice one complete stroke. Compression is obtained at the expense of power, and the piston

moves twice backwards and forwards for every explosion or motor impulse given to the crank shaft. The well-known Otto engine is a typical example.

In Type II., *Class b*, there is the same cycle of operations as in Class *a*, but instead of sacrificing a stroke of the motor piston, a special auxiliary cylinder is added. Admission of the charge in the pump, and expansion in the motor cylinder, are effected simultaneously; the return stroke in the pump compresses the charge, while the motor piston drives out the products of combustion, as in the Clerk engine.

There are very few engines which do not belong to either of these types. These are chiefly six-cycle engines, where the operations are similar to those described in *Type* II., *Class a*, but a third complete stroke is added, in order to cleanse the cylinder thoroughly of the products of previous combustion by what is called a "scavenger" charge of pure air. To avoid the difficulty of having only one motor stroke in six, these engines are sometimes made double-acting—that is, an explosion takes place alternately at either end of the cylinder at every third stroke. Thus there are two impulses for every three revolutions, as in the well-known Griffin engine. The action of these different types will be fully explained later on.

It must be remembered that, in describing the to and fro motion of the piston of an engine, and its action on the crank, there are always two strokes, the forward or motor stroke, and the return or exhaust stroke. The forward or up stroke is towards the crank, the return or down stroke is away from the crank. The position of the piston corresponding to the outer dead point is when it is nearest to the crank shaft, and that corresponding to the inner dead point when it is farthest away from the crank. These terms will be used in this work.

The following table exhibits the different types and their cycles. The engines are assumed to be horizontal, except when otherwise mentioned:—

Type I.—Non-compressing.

	Cycle of operations.
Class a. One explosion per revolution—one cylinder. (Example, Lenoir.)	1. Forward or *motor* stroke—admission of charge of gas and air; ignition, explosion, expansion. 2. Return stroke—discharge of gases.
Class b (vertical only). One explosion per revolution—one cylinder. (Example, Atmospheric engine.)	1. Up stroke—admission of gas and air; ignition, explosion, expansion. 2. Down or *motor* stroke—discharge of gases.

Type II.—Compressing.

	Cycle of operations.
Class a. One explosion per two revolutions —one cylinder. (Example, Otto.) (Called the Otto cycle, or four-cycle.)	1. Forward stroke — admission of gas and air. 2. Return stroke—compression. 3. Forward or *motor* stroke—ignition, explosion, expansion. 4. Return stroke — discharge of gases.
Class b. One cylinder and one pump—one explosion per revolution. (Example, Clerk.)	1. Forward or *motor* stroke — in cylinder—ignition, explosion, expansion; in pump—admission of gas and air. 2. Return stroke—in cylinder—discharge of gases; in pump—compression.

CHAPTER III.

HISTORY OF THE GAS ENGINE.

CONTENTS.—Early Combustion Engines—Gas Engines by Hautefeuille, Huyghens, Papin, Barber, Street, Lebon, Brown, Wright, Barnett, Drake, and others—Use of Town Gas for Engines—The Barsanti and Matteucci Patents.

Early Combustion Engines.—The earliest attempts to obtain motive power from heat were made by igniting inflammable powder, and utilising the force of the explosion thus generated. As a source of energy, this combustible powder was the first agent used; it preceded the production of coal gas, or steam. Strictly speaking, cannons are the oldest heat motors, and the principles on which they are constructed are identical with those of internal combustion engines. Heat is applied to explosive powder. and the combustion and expansion of the powder furnishes the motive force to propel a ball forward. In modern heat engines a piston takes the place of the ball. In the early days of mechanical science, the energy shown in the projection of a cannon ball seemed to afford a simple solution of the problem how to obtain power and motion by heat. But the power produced by exploding powder in a cannon could not be used for practical work, because it was not generated continuously and regularly. To apply the expansive force of the gases given off during combustion, the combustible was exploded in a closed vessel, and made to act upon a piston. These early

combustion engines were the forerunners of modern gas motors, in which the power is also obtained by explosion. But though they were introduced nearly a hundred years before the first steam engine, they were soon abandoned, because it was found impossible to control the power generated. Steam was easier and safer to work with, and for more than a century explosive engines were wholly relinquished.

Hautefeuille.—The first to propose the use of explosive powder to obtain power was the Abbé Hautefeuille, the son of a baker at Orleans. To him belongs the honour of designing, not only the first engine worthy of the name, but the first machine using heat as a motive force, and capable of producing a definite quantity of continuous work. As such, he may be considered one of the originators of heat motors. In 1678 he suggested the construction of a powder motor to raise water. The powder was burnt in a vessel communicating with a reservoir of water. As the gases cooled after combustion a partial vacuum was formed, and the water was raised by atmospheric pressure from the reservoir. Another machine described by him in 1682 was based on the principle of the circulation of the blood, produced by the alternate expansion and contraction of the heart. Here the water was raised by the direct expansive action of the combustible gases given off by the powder when ignited. This was the first instance of a direct-acting engine, but no machine could be made strong enough to resist the spasmodic expansion of powder, as here proposed.

Huyghens, Papin.—Hautefeuille does not seem to have actually constructed the machines he designed; but Huyghens, who was the first, in 1680, to employ a cylinder and piston, constructed a working engine, and exhibited it to Colbert, the French Minister of Finance. The powder in this motor was ignited in a little receptacle screwed on to the bottom of a cylinder. The latter was immediately filled with flame, and the air in it was driven out through leather tubes, which by their expansion acted for the moment as valves. The piston was forced by the pressure of the atmosphere into the vacuum thus formed. This is the action shown in modern atmospheric gas engines, but Huyghens found a difficulty in getting his valves to act properly, and in 1690 an endeavour was made by **Papin** to improve upon his principle. By providing the valves with hydraulic joints, Papin contrived to make them tighter, and to obtain a better vacuum, but he found that, in spite of all his efforts, a fifth part of the air still remained in the cylinder, and checked the free descent of the piston. After various attempts to overcome this difficulty, he abandoned the use of explosive powder, and devoted his attention to steam.

Barber.—For more than 100 years after these early attempts, all the efforts of scientific men and inventors were directed to

the study of steam, and its applications to produce power. For the time there was no other known agent that could compete with it. Gas extracted from coal had not yet been applied as a motive force in engines, and experience had shown that explosive powders were too dangerous, and too intermittent in their action, to be used with safety. The first to design and construct an actual gas engine was John Barber, who took out a patent (No. 1833) in 1791. Various circumstances contributed to the success of his invention. The steam engine already occupied an important position in mechanical science, thanks to the genius of Watt, Newcomen, Smeaton, and others. Workmen had by this time been trained, able to turn out and adjust with fair precision the different parts of an engine, though good tools were still hardly to be obtained. The distillation of gas from coal had already been discovered by Dr. Watson, though it was not till 1792 that Murdoch, a Cornish engineer,* applied it to practical use. Barber made the gas required for his engine from wood, coal, oil, or other substances, heated in a retort, from whence the gases obtained were conveyed into a receiver and cooled. A pump next forced them, mixed in proper proportion with atmospheric air, into a vessel termed the "Exploder." Here they were ignited, and the mixture issued out in a continuous stream of flame against the vanes of a paddle wheel, driving them round with great force. Water was also injected into the explosive mixture to cool the mouth of the vessel and, by producing steam, to increase the volume of the charge. Barber's engine exhibits in an elementary form the principle of what is now known as combustion at constant pressure, but it had neither piston nor cylinder.

Street.—The next engine, invented by Robert Street, and for which he took out a patent (No. 1983) May 7th, 1794, was a great step in advance. Inflammable gas was exploded in a cylinder and drove up a piston by its expansion, thus affording the first example of a practical internal combustion engine. The gas was obtained by sprinkling spirits of turpentine or petroleum at the bottom of a cylinder, and evaporating them by a fire beneath. The up stroke of the piston admitted a certain quantity of air, which mixed with the inflammable vapour. Flame was next sucked in from a light outside the cylinder, through a valve uncovered by the piston, and the mixture of gas and air ignited. The explosion drove up the piston, and forced down the piston of a pump for raising water. In this engine many modern ideas were foreshawdowed, especially the ignition by external flame, and the admission of air by the suction of the piston during the up stroke, but the mechanical details were crude and imperfect.

* The first practical application of gas to lighting purposes was in 1798 at the Boulton and Watt Soho Factory near Birmingham, where Murdoch was then employed.

Lebon.—A great improvement in the practical application of gas engines was made by Philippe Lebon, a French engineer, who obtained a patent, Sept. 28th, 1799, and a second in 1801. The first was more particularly intended to describe the production of lighting gas from coal; in the latter he proposed to utilise this gas to drive a piston in an engine very similar to that designed by Lenoir, sixty years later. The inflammable gas and "sufficient air to make it ignite" were introduced separately into the cylinder on both sides of the piston, and the inventor proposed to fire the mixture by an electric spark. The machine was double acting, and the explosions of gas took place alternately on each side of the piston. The most striking peculiarity of the engine was the piston-rod, working not only the motor shaft, but through it two pumps, in which the gas and air were compressed, before they entered the motor cylinder. Lebon also suggested that the machine generating the electric spark should be driven from the motor shaft. The excellent theoretical principles on which this machine had been designed were striking at that early period, and marked a new era in gas engines. More than sixty years elapsed before the great advantages Lebon had so clearly understood, of compressing the gas and air before ignition, were fully realised. The progress of mechanical science was perhaps retarded for many years by the assassination of this skilful engineer in 1804, before he had time to perfect the details of his invention. But in any case Lebon's engine was too much in advance of the times to have achieved immediate success. The manufacture of gas from coal was still in its infancy, and it was too expensive and difficult to produce to be used for driving an engine, while electricity was at that period so imperfectly understood, that the ignition of the charge by an electric spark was alone sufficient to condemn the motor.

Brown.—Lebon had many imitators, especially in France, but the next to invent a practical engine was an Englishman, Samuel Brown, who took out two patents, No. 4874, in 1823, and No. 5350, in 1826. Brown's gas engines were the first actually at work in London and the neighbourhood, and also the first in which the pressure of the atmosphere was utilised as a motive power. The principle in both was the same, viz., to produce a partial vacuum in a cylinder by filling it with coal gas flames, which drove out the air; the products of combustion were instantly cooled, and the vacuum thus obtained utilised to drive a piston. Instead of explosion, combustion of the gases was obtained by lighting them by a small flame as they entered the cylinder. The temperature of the latter was reduced by a water jacket, and water was injected to help the vacuum. In his first engine Brown employed two cylinders and pistons, connected by a beam. One piston was driven down by atmospheric pressure at one end of the beam, while the other, connected to the other

end, was simultaneously raised. Part of the air escaped through valves in the piston, and the burning gases being instantly cooled by the water injected, condensation was produced, and a vacuum formed. In his second gas engine several cylinders were used, to obtain a continuous vacuum. The working action was the same, but the air escaped through the valve covers of the cylinders, which were successively lifted. As in the other engine the gases were cooled, after combustion, by the injection of water. These engines were, however, cumbrous and difficult to work, and the expense of driving them with coal gas soon stopped their manufacture. A drawing is given in Robinson's *Gas and Petroleum Engines*, p. 105.

Wright.—The next improvement in gas motors was the use of a governor to control the speed, introduced by Wright in his vertical double-acting engine, patented 1833 (No. 6525). Wright's engine had one cylinder and piston, and one explosion was obtained alternately at either end of the cylinder. The piston and piston-rod were hollow, and the cylinder had a water jacket to counteract the intense heat of the double explosion. Ignition was obtained by an external flame and a touch hole. The gas and air were slightly compressed in separate reservoirs, before entering the motor cylinder; their admission was regulated by a centrifugal governor, and the richness of the mixture, or the greater or less quantity of gas passing the valve, varied with the speed. The design of this engine was carefully thought out, and its practical working details had not been overlooked, but it appears doubtful whether it was ever made.

Barnett.—Five years later, in 1838, William Barnett, another Englishman, took out patents for three vertical engines. These engines contained so many novel and interesting features, and anticipated in so many ways the latest improvements of modern science, that they mark an important advance in the construction of gas motors.* The first (patent No. 7615) had one working cylinder, single acting. Gas and air were drawn in and compressed by two pumps, and passed into a receiver below the motor cylinder, where they were mixed. During the down stroke of the pumps, while the charge was being forced into the receiver at a pressure of about 25 lbs. per square inch, the return stroke of the motor piston was discharging the burnt gases through the exhaust. All three pistons moved simultaneously up and down. As the motor piston reached the bottom of its stroke, a valve at the side opened communication with the receiver. At the same time a revolving ignition cock immediately above the exhaust fired the mixture issuing from the receiver, and the burning gases entered the motor cylinder

* A drawing of Barnett's engine is given in the *Proceedings of the Inst. Mechanical Engineers*, 1889.

through the admission port, and impelled the piston upwards, as the crank passed the dead point.

The conical ignition cock, two views of which are shown at Fig. 1, is well designed, and has formed the type for many similar arrangements. It consists of a hollow revolving plug, A, in a shell, B. There are two openings, *d* communicating with the outer air, and *e* facing the cylinder; the conical plug itself

Fig. 1.—Barnett's Engine Gas Ignition Cock—Longitudinal and Transverse Section. 1838.

has only one port. At the bottom of the shell is a gas jet, which, when lighted, is in the centre of the hollow plug. As the plug revolves, the slit in it is brought opposite the port, *e*, of the shell communicating with the cylinder, and part of the highly-compressed gases pass into the hollow plug, and fire the charge. The flame itself is blown out by the force of the explosion; but, as the plug continues to revolve, the slit is brought to face port *d*, opening to the atmosphere, on the outside of which is a permanent second gas flame, H. Here the light is rekindled, each time it is brought round by the revolving plug.

Barnett's second engine was double acting, but in principle it resembled the first. The third engine in its mechanical details differed very little from the gas motors now in use, and modern inventors have found it difficult to improve upon it in theory. One defect of Barnett's former engines was that, as the receiver or charging cylinder was never swept out by the piston, a portion of the gases of combustion was not displaced by the new compressed charge of gas and air, but always remained in it. Barnett proposed to overcome this difficulty by the use of an exhaust pump; but in his third engine he abolished both pump and receiver. The gas and air were compressed in separate cylinders, and delivered direct into the motor cylinder. The pump shaft was driven by a pair of wheels from the motor crank shaft, and the pumps made twice as many strokes as the motor

piston. The engine was double acting, and the compressed gas and air were admitted alternately to each face of the piston. The action of the engine and exhaust valve was as follows:— The piston being at the bottom of the cylinder, the compressed charge below it was fired by the ignition cock in the same way as in the single-acting engine. The piston drove up before it the products of combustion from the last explosion, and discharged them during the first half of the stroke into the atmosphere, through a port in the centre of the cylinder. As this port was closed by the piston, the pressure below it fell to that of the atmosphere. The gas and air, already compressed in the pumps, were then delivered into the top of the cylinder, and still further compressed by the continued up stroke of the motor piston, together with a certain quantity of the gases of combustion left from the former charge. The mixture at high pressure was fired, and the piston driven down by the explosion, forcing out the burnt gases below it in the first part, and compressing the residuum with the fresh charge during the second part of the stroke. At the bottom of the cylinder a fresh explosion took place, and the cycle was repeated.

Barnett may justly claim the honour of having been the first to introduce compression of the gas and air in a practical shape, as now used in gas engines. Lebon, it is true, proposed to compress the mixture slightly before igniting it, but he did not work out the details, or put his method to the test of actual practice. There are three points distinguishing Barnett's from previous engines. Ignition was effected at the dead point, and gave an impetus to the crank and piston during the whole forward stroke; the gas and air were compressed before ignition; and part of the products of combustion were utilised to increase the pressure in the motor cylinder. It is generally admitted, however, that Barnett did not recognise the merit of his own suggestions. Experience has shown that compression is essential to economy in a gas engine, and ignition at the dead point is also important, but Barnett apparently used both, without realising their value. Nor did he seem aware of the difficulties of disposing of the gases of combustion, a point on which later inventors have differed so widely; for although he attempted to discharge the greater part, he evidently did not regard the presence of the remainder as affecting the explosion of the mixture. In the opinion of Mr. Clerk, insufficient expansion was the fault of the later Barnett engine, a defect which it has hitherto been found impossible to avoid in double-acting engines.

Two or three smaller engines were designed during the next twenty years, although none of them seem to have been constructed. In 1841 Johnston described a motor in which he proposed to introduce oxygen and hydrogen gas into the cylinder,

and fire them. The force of the explosion drove up the piston, and a vacuum was produced by the condensation of the gases. The same process was repeated at the top of the cylinder, and the piston was forced down by the fresh explosion, ascending and descending alternately in a vacuum. The great cost of these gases was sufficient to condemn Johnston's project of what may be called a condensing oxy-hydrogen engine.

Between the years 1838 to 1860 a large number of patents were taken out both in England and France, but most of the engines never advanced beyond the specification. Sixteen patents were granted from 1850 to 1860. Among the engines designed were—Ador, 1838; Robinson, 1843; Reynolds, 1844; Perry, 1845; Brown, 1846; Roger, 1853; Bolton and Webb, 1853; Edington, 1854, and others. A few contain novel though impracticable features, and are described below, because, as inventions, they are interesting.

Drake.—An ingenious gas engine was exhibited by Dr. Drake at Philadelphia in 1843; the English patent (No. 562) was taken out in 1855 by A. V. Newton. In this horizontal engine ordinary lighting gas was used, mixed with nine or ten times its volume of atmospheric air. Much care was taken to admit the mixture in proper proportions, and the supply of gas was regulated by valves controlled by a governor. The charge entered the cylinder at atmospheric pressure, and was fired by a small tube kept at white heat by an external flame. The force of the explosion drove out the piston, giving a maximum pressure of about 100 lbs. per square inch; the mean effective pressure during the stroke, with a speed of sixty revolutions, and twenty indicated H.P.,* was about 36 lbs. per square inch. The cylinder had a water jacket, and the piston was hollow. The engine was originally double-acting, but when used in America it worked single-acting only; the valves on one side of the piston were kept always open to the atmosphere. The force of the explosion was very great, and owing to defective construction was chiefly directed against the cylinder heads, shaking the whole machinery. The engine was afterwards modified, and worked chiefly with petroleum.

An important suggestion, which has since formed the basis of many successful engines, was made by Degrand in 1858. He proposed to compress the charge in the cylinder by the motor piston, but the idea was abandoned at the time, because Degrand required a large cylinder to obtain previous compression.

None of these engines worked successfully, and many were never made. One cause of their failure, which has not been much noticed by writers on the subject, was the difficulty

* H.P. = Horse-Power.
I.H.P. = Indicated Horse-Power.
B.H.P. = Brake Horse-Power.

of procuring lighting gas from coal, except in a few of the large towns. The art of distilling gas was still in its infancy, and possibly few of the early inventors foresaw the day when gas would become a household commodity, as easily obtained, even in small villages, as water. Sixty years ago, it was costly and seldom available, and numerous substitutes, none of them very practical, were proposed. As gas was more extensively made it became much cheaper; engineers saw in it a new motive power, concentrated their efforts to utilise it, and finally achieved success. Another mistake made by the early inventors of gas motors was, that they attempted to supplant, instead of to supplement, the steam engine. They did not perceive the real advantages of the gas engine as a motor for small powers, but tried to make economical engines up to 20 H.P., or 50 H.P., before the constructive details were thoroughly understood. A third difficulty in constructing practical gas engines lay in the ignorance prevailing on the subject. They were designed too much on the lines of steam engines. Most of the latter were double acting, and the inventors of the day could not divest their minds of the idea that a similar method, if adopted with gas, would give the same favourable results. Experience has shown that the action of gas in a cylinder is very different from that of steam, and that gas engines must be differently designed.

Barsanti and Matteucci.—At about this period, however (1860), and especially after the production of the Lenoir and Hugon engines, three defects had come to be recognised as the inevitable results of an explosion at each to and fro stroke of the piston. The heat generated was so great that it had to be carried off as quickly as possible, and even with water jackets to the cylinder, parts of the engine sometimes became red hot. It was also impossible, in a double-acting engine, to compress the gas and air before ignition; and lastly expansion of the gases was greatly limited. The stroke of the piston was too short to utilise to the full the expansive force produced by the explosion, and the products of combustion were discharged at a pressure much above atmospheric. In this way, almost all the heat generated by the ignition and explosion of the gases was wasted. Many experiments were made, and many engines constructed, before it was realised that the greater the amount of heat utilised by doing work on the piston, the lower would be the temperature and pressure of the gases at discharge, and the less heat would be wasted. The next engine, invented by two Italians, Barsanti and Matteucci, showed a better knowledge of the principles of economy. In it a distinct step in advance was made, and an important principle exhibited for the first time in practice, namely, the use of a free piston, and unchecked expansion of the charge. For this reason Barsanti and Matteucci's motor deserves attention

and study, though, like many others, it was not a practical working success.

In this vertical atmospheric engine, as in Barnett's first motor, the idea of a cylinder closed at both ends is abandoned. Explosion takes place at the bottom of the cylinder, the piston is free and not connected during the up stroke to the crank shaft. The motive force is exerted only during the down stroke. A partial vacuum being produced below the piston by the cooling of the exploded gases, it descends by the atmospheric pressure above it, plus its own weight. This is the first example of an indirect vacuum engine with free piston. Gas and air are admitted at atmospheric pressure through slide valves into the cylinder, where they are partly mixed, and fired by an electric spark. The piston is driven up by the explosion, without any check to its velocity, or to the expansive energy of the gases. Before it reaches the top of its stroke the explosive force is expended, but it is still urged upwards by the weight of the different parts in motion. It is there brought to a stand by the pressure of the atmosphere, and begins to descend; a rack on the piston-rod catches into a cog-wheel, driving the motor shaft with it in its descent, and giving the positive or useful work performed by the engine.

Fig. 2.—Barsanti and Matteucci's Gas Atmospheric Engine. 1854.

Two patents were taken out by Barsanti and Matteucci in England, the first in 1854, the second in 1857. In the first the free piston was supplemented by a lower auxiliary piston immediately below it in the same cylinder. An outline drawing of the engine is shown at Fig. 2. A is the cylinder and P the motor piston; *p* is the auxiliary piston, S the flat slide valve actuated by a lever, F, connected with the rod E of the auxiliary piston, which passes through the bottom of the cylinder. The crosshead at E is attached by two levers, not shown in the drawing, to the wheel D and the crank J, driven from the main shaft, but not revolving so rapidly. As soon as the free piston P has reached its lowest position *p* begins to descend, and air is admitted between the two pistons through the passages *a*, *b*, *c* of

the slide valve S. As the auxiliary piston descends, the slide valve is lowered with it by the lever F, the air port *a* is closed, and the gas port *d* uncovered, admitting gas to the cylinder between the pistons, through *d*, *b*, and *c*. The slide valve next shuts off *d*, when the mixture is fired by a series of electric sparks, the circuit being put on by the lever F. The piston P which has been at a stand, is now projected upwards, and *p* is forced still lower, driving out the products of combustion below it through the openings *i i* in the bottom of the cylinder. The pressure in the cylinder beneath the free piston is now below atmosphere, the valves *i i* close automatically, the channel *f* is uncovered, and as the piston rises, communication is established between the contents of the cylinder above and below the piston *p*, through *f*, *e*, and *b*. The working piston descends in the vacuum, driving out the exhaust, and the same process is repeated.

The arrangement of the catch is novel and ingenious. The rod of the free piston P carries a rack, and as soon as the piston begins to descend, the rack gears into the toothed wheel L, running loose on the main shaft K. The wheel L has a pawl C. As the rack falls, and drags L round to the right, the spring *s* presses the pawl C into the teeth of the ratchet wheel B, which is keyed on to the main shaft K, and causes B and therefore K to rotate to the right. When the piston rises, the main shaft continues to turn to the right, but the movement of the wheel L is reversed; it revolves to the left with the up stroke of the piston, and C, slipping past B, loses connection with the main shaft. To steady the motion of the engine two working cylinders and pistons were employed, driving the shaft alternately, and the flywheel also helped to regulate the speed. The rack and clutch gear form the basis of similar methods for utilising the down stroke in atmospheric engines, and have, with the free piston, been repeated with modifications in the Otto and Langen, Gilles, and others. In the Barsanti and Matteucci engine the modern slide valve was also first introduced, the main construction of which has since been retained, although the valve is often differently driven.

The second engine, patented by Barsanti and Matteucci, had the long vertical cylinder and piston with rack, but the auxiliary piston was abolished. The slide valve was worked by a valve rod, and the details were much simplified. There was an auxiliary as well as a motor shaft, both having pawls acting upon the rack. When the piston is in its lowest position, it is slightly raised by the pawl upon the main shaft. The valve rod is lifted at the same time by a smaller pawl on the auxiliary shaft, and air admitted through an outlet which serves also for the exhaust. As the piston and slide valve rise, the latter shuts off the air, and opens the gas port. The piston next overruns

this port, the mixture in the cylinder is fired by an electric spark, and the piston driven up as before, free of the main shaft. During its descent the piston-rod engages in the wheel and ratchet on the main shaft, causing the whole to revolve during the down stroke. As soon as the pressures above and below the piston are equalised, and its descent arrested, it is caught by the other pawl, and held down, to drive out the products of combustion. The movement of the slide valve is regulated in the same way by the two smaller pawls on the main and auxiliary shafts, acting on two projections on the valve-rod. The piston having reached its lowest position, is raised by the pawls upon the main shaft, to admit a fresh charge.

In this engine a much better and freer expansion was afforded to the combustible gases than had hitherto been obtained. In fact there was no check to their expansion, except the weight of the piston, &c. But, notwithstanding its excellent cycle, this motor was never in the market, probably because the working details and the mechanism were defective. That the main lines on which it was constructed were good, is proved by the fact that they were adopted and successfully put in practice by Otto and Langen, though the German engineers appear to have designed their motor independently. The fundamental principle of the Barsanti and Matteucci engine, to utilise the whole force of the explosion in as complete expansion as possible, was excellent, and has not been improved upon. Few modern inventors have been able to approach as closely the conditions of a perfect theoretical cycle.

CHAPTER IV.

HISTORY OF THE GAS ENGINE—(*Continued*).

CONTENTS.—Period of Application—The Lenoir Engine—Tresca's trials—Hugon's Engine, and Tresca's experiments—Siemens, Schmidt, Million—Beau de Rochas' Cycle of Operations.

ABOUT the year 1860 the importance of the gas engine had become widely recognised. Great as was the perfection to which steam engines had been brought, it was felt that they did not, and could not, supply the various requirements for an economical motor. The necessity for some other kind of engine had already been pointed out by Cheverton in 1826. In a letter to the Mechanic's Magazine he says—"It has long been a desideratum in practical mechanics to possess a power engine, which shall be ready for use at any time, capable of being put in motion without any extra consumption of means, and without a

loss of time in its preparation. These qualities would make it applicable in cases where but a small power is wanted, and only occasionally required. They are so numerous, and the consequent saving of human strength would be so great, that the advantages accruing to society would be immense, if even the current expense were much greater than that of steam." No words could better describe the present advantages of the gas engine.

Application.—In the history of gas motors three periods may be distinguished—1, Invention; 2, Application; 3, Theoretical and practical improvement. The first, the period of invention, was over. Hydrogen, inflammable powder, and other explosives were no longer used in engine cylinders, and gas was already recognised as the most suitable medium, next to steam, for utilising heat as a motive power. In the construction of the gas engine, much had been achieved by mechanical ingenuity. All the parts had been designed, and the details thought out. Scarcely a single improvement has been suggested in modern engines, which may not be found in the drawings of Lebon, Barber, Street, Barnett, and others. In the words of Professor Witz—"The gas motor had been invented; the problem was how to make it a working success." It is here that we enter on the second period, of Application. That time, too, has now passed. Practical experience has long been brought to bear on the construction of the gas engine, but the maximum utilisation of the heat is still a problem of the future.

Lenoir.—From this point of view, the honour of having invented and introduced the first practical working gas engine justly belongs to Lenoir. His specifications set forth no new features, but he was able, not only to make his engine work, which no one had hitherto succeeded in doing, but to work rapidly, silently, and, as at first supposed, more economically than steam. Cost and space were reduced by the absence of a boiler, and nothing could apparently be simpler, nor better suited to drive machinery of every kind, than the new motor. Its success was undoubted, and every one was eager to use it. The partisans of Lenoir loudly and confidently affirmed that the reign of steam was over, and that it would be immediately superseded by gas. The economy attributed to the Lenoir motor, and exaggerated by report, increased its popularity. Although made at a time when very little was known of the theory of the gas engine, and its action was imperfectly understood, the new motor was credited with an economy in the consumption of gas which inventors, after thirty years of study and experience, have hardly been able to realise.

Lenoir took out his first patent in France, Jan. 24, 1860; in England, No. 335, Feb. 8, 1860. The engines were made by M. Hippolyte Marinoni, a French engineer, whose mechanical skill

undoubtedly contributed to their success. During the first year one was constructed of 6 H.P. and another of 20 H.P., and so great was the demand that, in five years, between three and four hundred motors were made in France, and a hundred in England. This is a large number, considering that the gas engine was still on its trial. A Lenoir engine was used to propel a boat on the Seine, and for twenty years water has been pumped by another at Petworth. The construction was undertaken by the Reading Iron Works in England, and the Compagnie Lenoir at Paris. In 1863 the patent of the latter was acquired by the Compagnie Parisienne de Gaz.

The usual reaction from such undue praise and indiscriminate adoption of the new engine followed. The chief cause of its sudden fall in popular esteem was the discovery that it consumed much more gas than it was said to do. Some of the advocates of the new motor claimed a consumption of 31·7 cubic feet of gas per H.P. per hour; others instituted a comparison with the steam engine, to the disadvantage of the latter. Thus, it was asserted that the cost of working a 4 H.P. steam engine in Berlin was 6s. 6d. per hour; for a Lenoir engine of the same power it was said to be about half. These figures were greatly exaggerated. In practice the Lenoir engine consumed from 88 to 105 cubic feet of Paris gas per H.P. per hour. A brake experiment gave a mean of nearly 106 cubic feet, and this was about the average consumption for small powers. The quantity of water required for the cooling jacket was considerable. The heat generated was so great that, unless the engine was copiously oiled, the working parts were injured, and it was brought to a stand. Hence it was sarcastically said that "the Lenoir motor did not require heating, but oiling."

In the reaction which now set in most of the Lenoir engines were at once abandoned; some were broken up, and a few even turned into steam engines. This sweeping condemnation was hardly justified. The engines possessed many advantages, which were as completely overlooked as their defects had been at first. They were easy to transport, to fix, and to set to work, and, when constructed for small powers, were very useful in many cases for superseding manual labour. If the consumption of gas was heavy, the original cost of construction was said to be less than that of a steam motor. The engine could be started at a moment's notice, and when not running, no expense for gas was incurred, while it has hardly been surpassed for silent, smooth, and regular working. But these were not the chief merits of the Lenoir engine. It was the first to compete with steam for small powers, and to familiarise the public with the idea of obtaining motive power from gas. The advantages of these motors were so great and so patent that, when the Lenoir was gradually superseded, it was replaced by other engines driven by

gas. Its very defects acted as a stimulus to fresh efforts, and kept the subject before the minds of inventors. Once accustomed to the easy action of a gas engine, in which it was only necessary to turn a valve on the gas main, and another on the water supply, to set the machine in motion, many people refused to return to the laborious process of generating steam in a boiler.

Lenoir was himself fully alive to the faults of his engine, and continually studied to overcome them, but he started from a wrong basis. He attributed the extravagant consumption of gas to the rapidity of explosion, which affected the action of the engine injuriously, by producing a sudden rise and fall in the pressure. In common with later inventors, he endeavoured to diminish the force of the explosion, and to obtain a slower combustion of the gases by stratification, and in a second patent, No. 107, January 14, 1861, he also proposed to inject a little water into the cylinder. In his opinion it would help to lubricate the engine, take up by evaporation some of the heat developed, and, above all, cool the charge and retard explosion. The injection of steam into a gas engine cylinder has since been often suggested, and put in practice, without producing any real economy—its advantages and defects will be considered later on. Lenoir himself does not seem to have carried out his proposal.

The much vaunted and much abused Lenoir gas engine resembled in construction a double-acting horizontal steam engine, and the gas was ignited electrically. Gas and air were admitted at both ends, drawn in by the piston during the first part of the stroke, and then fired and expanded. Admission of the charge was cut off, either at half stroke or a little later. As ignition with the electric spark was sometimes retarded, it occasionally happened that the piston had passed through a considerable portion of the stroke before explosion occurred, and incomplete expansion was the result. The cylinder, both covers, and the chamber into which the gas was admitted, were water-jacketed, and the circulating water was used over and over again.

In the original drawing of the engine, shown at Fig. 3, A is the motor cylinder, in which is the piston P. The piston-rod works the connecting-rod C, and crank shaft K, through the crosshead D. Two eccentrics, G and H, on the crank shaft, work two flat valves, S and S_1, on either side of the cylinder. The slide valves, S S, admit gas and air into the cylinder, and those at S_1 S_1, allow the products of combustion to escape. The latter each contain one exhaust port; and these are brought into line with the exhaust openings shortly before the end of the stroke, to let out the gases of combustion, and close over them as the fresh mixture enters. Through the exhaust ports the

gases pass into a discharge pipo, and thence into the atmosphere. The slide valves, S S, perform the functions of admission and distribution, and the two chambers, L L, are filled with gas.

Fig. 3.—Lenoir Horizontal Gas Engine. 1860.

These valves are made with small cylindrical holes $\frac{1}{12}$ inch in diameter, alternating with larger apertures $\frac{1}{4}$ inch by $\frac{1}{2}$ inch diameter. The gas enters from L through these holes, while the air is admitted through the ends of the slide valves, which are open to the atmosphere, and passes through the apertures in the proportions of about 1 of gas to 12 of air. This arrangement of comb-shaped grooves and passages is continued throughout the whole thickness of the slide, and the effect is to cause the gas and air to flow to the cylinder in separate streams. By thus forcing them to enter without mingling, a better stratification of the charge was supposed to be obtained. Lenoir's idea seems to have been that the ignition flame would be propagated from one stratum of gas to the next, through the dividing layers of air, but this appears doubtful, and it has been questioned whether any real stratification of gas and air takes place. At either end of the cylinder is a small projection at b and b_1, to which wires are attached from the coil and electric battery, M.

The action of the engine is as follows:—The exhaust valves being closed when the piston is at the extreme end of the stroke, as shown in the drawing, the energy of the flywheel is sufficient to carry it forward. The air port, which is very large to prevent throttling, is already slightly open, the gas valve now opens, and

Air

Fig. 4.—Lenoir Engine—Section of Cylinder. 1860.

the charge is mixed in the main port of valve S before being drawn into the cylinder by the forward stroke of the piston. Meanwhile the pressure on the other side of the piston has been reduced to that of the atmosphere. Before the admission valve is completely closed the electric spark fires the mixture, and the piston is thus propelled forward to the end of the stroke, the

pressure rising to 5 or 6 atmospheres, but the action of the water jacket cools the cylinder, and reduces the pressure. The exhaust valve has a slight lead, and opens a little before the end of the stroke, allowing the gases of combustion to escape at a pressure of 1·5 to 1·8 atmosphere. The same process is repeated during the return stroke. A certain proportion of the gases of combustion are always left in the cylinder, but their pressure is low, and the clearance spaces are very small. The temperature of the escaping gases is given by Professor Schöttler at about 200° C. In an experiment by Tresca it was 220° C.

Fig. 4 gives a sectional plan of the cylinder, in which the admission of gas and air are slightly modified; the parts are lettered as in Fig. 3. Here the main admission port is open to the atmosphere, and is covered with a perforated brass plate, which extends downwards, so as also to cover the gas port. As the gas enters, it is forced to pass up and down through small holes in the metal plates, and to mix thoroughly with the air before entering the main port, but this arrangement, like that already described, was not found to work quite satisfactorily.

Like most of the early gas engines, the Lenoir was ignited by an electric spark, as shown at M, Fig. 3. A battery with two Bunsen cells, connected by a Ruhmkorff induction coil, and an electric hammer, produces a continuous stream of sparks. The contact maker N is in connection with the crosshead D, and piston-rod, through which the negative current passes, and the mass of the engine is negative. The positive current passes through wires insulated in porcelain tubes, leading from the two ends of the contact maker to the two projecting points, b and b_1, at each end of the cylinder. Contact is formed alternately between them by a projection moved to and fro by the crosshead. Although carefully designed, this apparatus was open to some of the usual defects of this system of ignition; the points occasionally missed fire, and the spark was retarded, or failed.*

The speed of the engine was regulated in the ordinary way by a centrifugal governor acting on the gas admission valve, and the supply of gas was wholly cut off, as soon as the speed exceeded the normal limits. The oiling was always defective. Ordinary lubrication by hand was at first used, but this was soon found insufficient to counteract the great heat generated in a double-acting gas engine. The piston frequently became red hot and heated the incoming charge *before* ignition, a defect which later inventors have endeavoured always carefully to avoid; and the temperature was so high that, unless frequently and copiously oiled, the engine would not work.

It is always less difficult to start a non-compressing gas engine fired electrically than a compression engine, and the Lenoir motor was very easily set in motion. The flywheel was turned

* In the Lenoir engine, as then made at the Reading Iron Works, the electrical arrangement was modified.

by hand, and the piston moved forward, drawing in the explosive mixture. At the same moment electric contact was established, a spark fired the charge, and the explosion drove out the piston over the dead point, after which the engine worked automatically.

The earliest trials on record of any gas motor are those made by Tresca in 1861 on the Lenoir engine. The first experiments were on an engine of ½ H.P. with a speed of 130 revolutions per minute. The proportion of gas to air was one-tenth, the maximum pressure obtained 4·87 atmospheres, the consumption of Paris gas was 112 cubic feet per H.P. per hour. In a second trial of a 1 H.P. engine, the quantity of gas used was reduced to 96 cubic feet per H.P. per hour, or about four times the average present consumption. The maximum pressure in the cylinder was 4·36 atmospheres, number of revolutions 94, and the proportion of gas to air 1 to 7½. In both engines more than half the total heat was carried off in the water jacket, and Tresca calculated that only 4 per cent. was utilised in useful work, the remainder being discharged with the exhaust gases. The average consumption of oil was about ·10 lb. per hour. Other experiments were made by Lebleu, Eyth, and Auscher, and an important trial was carried out by Mr. Slade in America. The engine tested was about 2 H.P., and ran at 45 and 50 revolutions per minute. The maximum pressure in the cylinder was 63 lbs. above atmosphere; the consumption of gas was not determined. Fig. 5 shows an indicator diagram of the Lenoir engine.

Twenty-five years later Lenoir, who was incessantly endeavouring to perfect his invention, brought out a single-acting compression engine, using Beau de Rochas' four-cycle. It will be described among modern motors.

The success of the Lenoir engine produced a host of imitators and rivals, several of whom set up a prior claim to the invention.

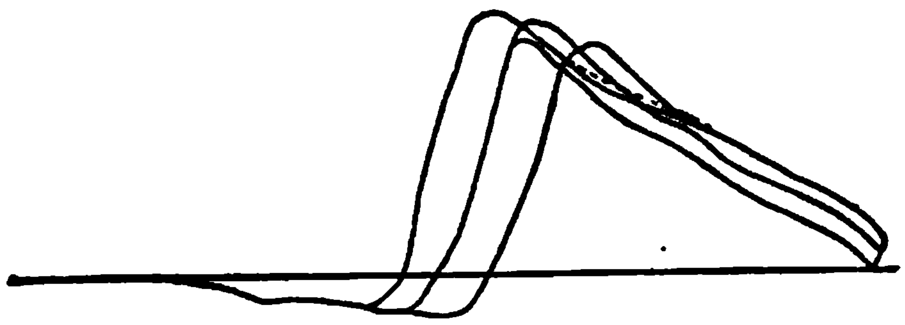


Fig. 5.—Lenoir Engine—Indicator Diagram (Slade). 1860.

Reithmann, a watchmaker at Munich, declared that he had designed an engine similar to Lenoir's, for which he had taken out a patent, Sept. 11, 1858. It was described in the "Bayerische Kunst und Gewerbeblatt," but, if ever made, it never reached a practical stage. A more formidable opponent was Hugon, the Director of the Paris Gas Company, whose original patent also dates from Sept. 11, 1858. It is certain that Lenoir worked independently, and that his invention as a practical engine was the first in the market.

Hugon.—Hugon's vertical gas engine did not appear till 1862. His original intention, as stated in his first patent, was to construct an atmospheric engine and utilise a vacuum. He abandoned it in favour of a direct-acting engine similar in principle to Lenoir's, which he patented in France, March 29, 1865 (No. 66,807). In this engine Hugon introduced several novelties and improvements. Flame ignition was substituted for electricity, and a small quantity of water was injected into the cylinder at every stroke, to cool and lubricate it, and to economise the consumption of oil. The arrangement of the slide valves, although complicated, was ingenious. The flame to ignite the charge was carried to and fro in a cavity inside the valve, and Hugon's engine afforded the first practical illustration of this method of ignition, afterwards so generally used. The defects of Lenoir's engine were the great heat generated, retarded ignition, and insufficient expansion of the charge. These faults Hugon hoped to avoid by flame ignition and the injection of water, and it cannot be denied that his engine was superior in economy, and in certainty and rapidity of explosion. Firing the gases by a permanent flame was an improvement on electricity as then employed, but the consumption of gas was still very large. The engine did not find much favour, even in France, nor supersede the Lenoir to any great extent, though it worked smoothly and, except from the economical point of view, satisfactorily.

In this vertical, single cylinder, double-acting engine, air and gas are admitted, as in the Lenoir, on both sides of the piston at atmospheric pressure. The piston P and piston-rod in cylinder A drive the shaft through a forked connecting-rod and crank, as shown in Fig. 6, taken from Schöttler's* careful description of the engine. An eccentric on the same shaft works the rubber gas reservoir C, from which the gas is pumped under slight pressure through the pipe *a* to the cylinder. A smaller gas reservoir, D, supplies gas for the ignition flames. The valve rod, actuated by a second eccentric on the crank shaft, works the two admission valves, S and S_1. A small pump, B, is driven from it, and injects water into the cylinder through the supply pipe *d* and the small openings d_1 and d_2. The main slide-valve S has five openings, *e* and e_1, the igniting ports containing the two gas jets for lighting the mixture at each end of the cylinder; *g* and g_1, the admission ports which receive the mixture of gas and air from the tube *a*, through the openings in the auxiliary slide S_1; and *h* the exhaust valve, discharging through K into the atmosphere. In the second and smaller slide valve, S_1, there are only two ports for opening communication between the main slide valve and the gas reservoir C. By the action of this slide valve the sudden admission and cut off of the slide are

* Schöttler, *Die Gas Maschine*, p. 23.

obtained, which form a principal feature of the Hugon engine. The valve is driven by the same valve-rod as the valve S, through a pin working in a slot; *f* and f_1 are permanent gas jets to rekindle the flame at *e* and e_1, when blown out, as it is each time, by the force of the explosion. There are two main ports, serving alternately for admitting the charge to the cylinder and igniting it, and for discharging the gases of combustion into the exhaust; this arrangement has since been altered

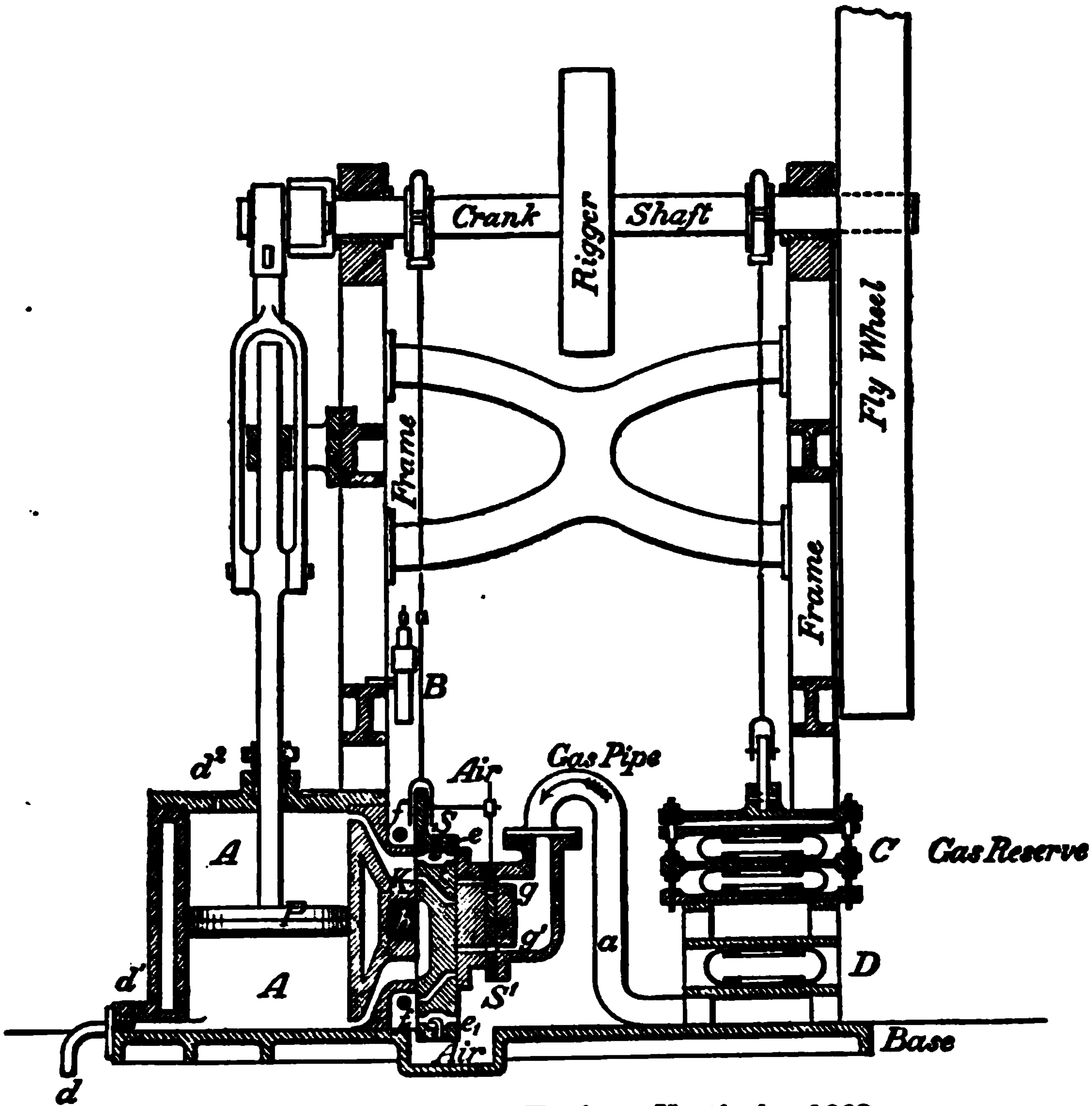


Fig. 6.—Hugon Gas Engine—Vertical. 1862.

The action of the engine is as follows:—When the piston is at the top of its stroke and begins to descend, the principal slide valve S is driven down, and the port *g* comes immediately opposite the upper main cylinder port, forming a connection between it and a port in the outer slide valve S_1, admitting gas and air from C through *a*. At this part of the stroke, the position of the slide valves is the following:—The light at *e* is in process of kindling by *f*, *g* is opening on to the main port, while at the bottom of the piston the products of the last explosion are dis-

charging through h into the exhaust. The port g being much smaller than the main port, the supply of gas and air through S_1 is soon cut off, but the communication of g with the main port is still open when the slide is suddenly driven down by the movement of the eccentric on the shaft. The gas flame e is brought opposite the inflammable mixture, and spreads through it, and back into the admission port. Explosion takes place when the piston has passed through about four-tenths of the stroke, and drives it down through the remainder. The piston and slide valve now begin to rise, and the same process is repeated at the lower end of the piston and cylinder. As, however, the valve in its upward progress must again cross the admission passages in slide S_1 before reaching the top of the cylinder, gas and air would be admitted at the wrong moment, and rapid admission and cut off could not be obtained unless this valve were closed. It is driven down by the pin projecting from the main valve, which catches and carries it in the same direction. A spring then holds it in position, and does not release it until the slide S has begun to return.

The main ports, the clearance spaces at either end of the cylinder, and the small admission ports make up together a space in which about 30 per cent. of the total charge remains after combustion, instead of being discharged by the piston during exhaust. At the moment of ignition, this percentage of burnt products is much weaker than the fresh explosive mixture of gas and air. The incoming charge, cut off almost immediately by the down stroke of the piston, and brought directly after into contact with the flame, is easily and instantaneously fired. Explosion is far more rapid than in the Lenoir engine, and a longer time is afforded for expansion, and for the dilution of the fresh charge with the products of combustion. The explosive action being much surer, weaker mixtures can be employed, and in some of the experiments the proportion of gas to air was as low as 1 to 13·5.

The speed in the Hugon engine was regulated, as in the Lenoir, by a governor acting on the gas valve, and the admission of gas was entirely suppressed, when the velocity exceeded certain limits. The engine was lubricated in a similar way to a steam engine, but there was not the same necessity as in the Lenoir for a continual use of oil, because the water injected into the cylinder partly supplied its place. The motor was easily started by lighting the external and internal gas flames, and giving a few turns to the flywheel.

In 1866 and 1867 Tresca made two experiments in France on a 2 H.P. Hugon engine. In the first the speed was 53 revolutions, and the maximum pressure in the cylinder 3·27 atmospheres. The temperature of the discharged gases was 186° C., and the gas consumption 92 cubic feet of Paris gas per

H.P. per hour. In the second experiment the highest mean pressure was about 3·8 atmospheres, the temperature of the exhaust gases 190° C. The gas consumption was about 77 cubic feet per H.P. per hour, not including that used for the ignition flame. In an experiment made by Mr. Clerk on a ½ H.P. engine,

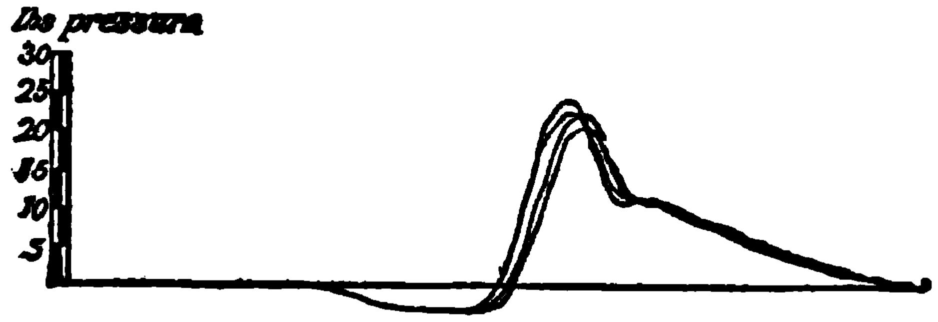


Fig. 7.—Hugon Engine—Indicator Diagram. 1862.

the maximum pressure was 25 lbs. per square inch, and the speed 75 revolutions per minute. Fig. 7 gives an indicator diagram of this trial.

Siemens.—About this time the subject of heat motors engaged the attention of Sir William, then Dr., Siemens, and he took out several patents for gas and hot air engines. His regenerative engine will be described in Part II. Although continually working on this subject, he does not appear to have constructed any engines, being so much occupied with other matters.

A few years later, a gas engine was brought out by Messrs. Kinder & Kinsey, closely resembling the Lenoir, but presenting no new features. The consumption of gas was said to be about 70·5 cubic feet per H.P. per hour.

The defect of both the Hugon and Lenoir engines was the large consumption of gas in proportion to work done. This extravagance checked the sale of these engines, and they ceased to be extensively made, even before others had been invented to take their place. Their failure was attributed to want of stratification. The gases were supposed not to be properly mixed, and it was hoped, by altering the arrangement of the valves through which they entered the cylinder, to remedy the defect. Inventors long thought it possible to distribute the admission of the charge in such a way, that the gas and air were introduced either in separate layers or thoroughly mixed. Both Lenoir and Hugon were of opinion that the shock given by the explosion was too violent, and needed to be weakened. These erroneous notions were gradually abandoned, and the real reasons of the want of economy were at last perceived, namely, insufficient expansion, and the absence of compression.

Schmidt—Million.—In 1861 Gustave Schmidt, in a paper submitted to the Institution of German Engineers,* declared that more favourable results would be obtained, greater expansion,

* *Zeitschrift des Vereines deutscher Ingénieure*, 1861, p. 217.

and better transformation of the heat of combustion into work, if the gas and air were previously compressed to two or three atmospheres. In the same year Million either re-discovered or was the first to apply practically Lebon's and Barnett's idea of previous compression of the gas and air. He took out an English patent, in which he proposed, like Barnett, to compress the mixture before admission by a separate pump, using the first part of the forward stroke to draw it into the cylinder. This idea he afterwards abandoned in favour of introducing the compressed gas and air, at the dead point, into a space at the working end of the cylinder, called a cartridge. Ignition followed, and the whole forward stroke of the motor piston was utilised in expansion. Million's proposals helped to develop the theory of the gas engine, but he does not seem to have put them into practice.

Thus the principle of compressing the charge of gas and air in an engine before ignition had already been foreshadowed, when a very remarkable descriptive patent upon the subject appeared in France in 1862 by M. Beau de Rochas. Hitherto the construction of gas engines had not been designed and worked out on a scientific basis. Inventors did not fully understand the effect of the different operations they proposed to carry out. They were ignorant of the reason why one engine gave more economical results than another, and what methods should be adopted to control the extravagant consumption of gas. They were all ready to recognise, without being able to remedy, the defects of their engines. Nor were study and perseverance wanting. Many of the earlier gas motors were the result of much labour and repeated experiments, and failed only for lack of a scientific comprehension of the subject.

Beau de Rochas.—The real reasons of the uneconomical working in the Lenoir and other motors were want of compression, incomplete expansion, and loss of heat through the walls.* In both the Lenoir and Hugon engines the pressures in the cylinder were always low and difficult to maintain, and this showed that the pressure generated by the explosion alone was insufficient, and must be increased by previous compression of the charge. Time was also lost in obtaining an explosion, and the heat, applied too late to the gas, was speedily dissipated, some of it going to heat the jacket water, and some being discharged at exhaust. M. Beau de Rochas, a French engineer, was the first to formulate a complete theory of the cycle of operations which ought to be carried out in a gas engine, to utilise more completely the heat supplied. Four conditions were laid down by him as essential to efficiency.

* The two latter defects, although to a certain extent controllable, are found more or less even in modern gas motors.

I. The largest cylindrical volume, with the smallest circumferential surface.

II. Maximum speed of piston.

III. Greatest possible expansion.

IV. Highest pressure at the beginning of expansion.

These working conditions are now generally admitted to be necessary, but at that time they created a revolution in the study of the gas engine. The first shows the reason why the consumption of gas was so much greater in small, as compared with larger engines. On this subject Mr. Dugald Clerk says, "As an engine increases in size, the volume of gaseous mixture used increases as the cube, while the surface exposed only increases as the square; so that the proportion of volume of gaseous mixture used to surface cooling is less, the larger the engine."

In the second and third conditions increased expansion and speed are insisted on. It was already known, or at least surmised, that unless the gases were as completely and quickly expanded as possible, much of the energy generated in the explosion was wasted. Only a small proportion was expended on the piston in doing work, and the gases escaped at too high a pressure. It was evident also, since a small cylinder wall surface was desirable, that the more rapidly the piston performed its stroke, the less time were the hot gases exposed to the action of this surface. "Other things being equal," says Beau de Rochas, "the slower the speed, the greater the cooling." Moreover the higher the speed of the piston, the more rapid and therefore the more perfect will be the expansion.

In Beau de Rochas' fourth condition a principle was embodied which contains the essence of the question, and the true secret of economy in a gas engine. The utilisation of the elastic force of the gases by prolonged expansion depended upon the high pressure of the charge, and this pressure could not be realised unless the gas and air were compressed previous to ignition. Compression was to be effected while the gases were cold, and the heat thus applied prolonged the expansion by increasing their pressure. By thus compressing the particles, an originally larger volume of the charge, containing more gas, can be introduced per stroke into the cylinder, and the pressure of explosion considerably raised. The advantages of compression are shown by the fact that the greater the pressure, and the more instantaneous the admission, the greater the economy within certain limits.

Beau de Rochas' Cycle.—To obtain these results Beau de Rochas considered it necessary to use one cylinder only, first, that it might be as large as possible, and secondly, to reduce the piston friction. In this cylinder the following cycle was to be carried out in four consecutive piston strokes:—

I. Drawing in the charge of gas and air.

II. Compression of the gas and air.

III. Ignition at the dead point, with subsequent explosion and expansion.

IV. Discharge of the products of combustion from the cylinder.

By the addition of the important principle of ignition at the dead point, the crank obtained the benefit of the impulse communicated by explosion and expansion during the whole of a forward stroke. This was not, however, the object specially aimed at by Beau de Rochas. He proposed to compress the gases to such an extent, that they ignited spontaneously at the dead point. The principle has since been adhered to in almost all modern gas engines, though it has generally been found impossible to obtain ignition of the gases by compression only. Each of the four operations generally requires one stroke of the piston, though in some cases compression is obtained by a separate pump.

This cycle, known as the four-cycle of Beau de Rochas, is the one now chiefly used in gas motors. It differs from that of Carnot because it is not a perfect or theoretical, but a practical, cycle. Many improvements have been effected in the mechanism of the gas motor, but they have all been founded on the sequence of operations and the working conditions described by Beau de Rochas. Next to compression, the most valuable innovations introduced by him were, carrying out all the operations in a single motor cylinder, and ignition at the dead point. But like many other scientific innovators, Beau de Rochas was in advance of his time. Fifteen years elapsed before what Professor Witz aptly calls "the programme traced of what ought to be attempted" was actually adopted, although now, thirty years after, its merit is universally recognised, and his cycle employed.

An award of 3,000 francs was presented to the veteran worker by the Société d'Encouragement pour l'Industrie Nationale in recognition of his valuable labours to advance the knowledge of the gas engine, and one of 2,000 francs by the Académie des Sciences. The "Société des Amis des Sciences" also assigned him a pension of 500 francs. M. Beau de Rochas died in 1892.

A translation of that part of his patent which relates to gas engine cycles will be found in the Appendix.

CHAPTER V.

HISTORY OF THE GAS ENGINE—(*Continued*).

CONTENTS.—The Otto and Langen Engine—Engines by Gilles, Hallewell, Brayton, and Simon—Ravel's Rotatory Engine—Ravel's Oscillating Engine—Foulis's Horizontal Engine.

THE construction of gas engines was meanwhile developed in a different direction to that indicated by Beau de Rochas. As it was seen that the expansion in the engines hitherto made was insufficient, an attempt was made to improve it by employing a free piston, giving in theory unlimited expansion. At the Paris Exhibition of 1867 the attention of scientific men was drawn to an engine patented by MM. Otto and Langen in 1866, and apparently of a new type, though it was really constructed on the same lines as that of Barsanti and Matteucci. It seems doubtful whether this new engine was more or less copied from the Italian's atmospheric motor, or whether the Germans worked independently. In any case they succeeded in making a practical engine, based on a principle which, owing to some mechanical defect in working it out, had been relinquished.

Otto and Langen.—In their main features the two engines were identical. At that time the idea was prevalent that the failure of the Lenoir and Hugon engines was due to the slow movement of the piston after ignition. Scientific men were agreed that the energy generated by explosion was rapidly diminished by the cooling action of the walls; if therefore expansion was retarded, much of the force obtained was dissipated. In an earlier patent taken out in 1863, the inventors of the Otto and Langen engine say—"Experience has shown that the interval of time which elapses between the heating and consequent expanding of the gases, and the subsequent cooling and consequent contraction, is but a very short one, and, therefore, in applying the expansive force of such heated gases as motive power, unless they are allowed to expand very rapidly—immediately after combustion has taken place—a great portion of the heat which should have produced such expansion will be absorbed by the cylinder of the engine, and consequently a great portion of the motive power will be lost." Hence, the principle of their engine was to obtain the most rapid and complete expansion possible after explosion. Theoretically this idea was right, but the mechanical difficulties of working it out have never been completely overcome, and though the

construction of the engine was continued for some years, it was eventually given up.

At the time of its first appearance, the Otto and Langen was the most economical engine till then introduced. Its consumption of gas, always comparatively low, was ultimately reduced to about 26 cubic feet per H.P. per hour, a quantity not greatly in excess of good modern gas engines. About 5,000 motors were constructed in ten years, and though never popular in France, the engine was at one time in great demand in England and Germany. As a practical working motor it was not satisfactory, but it marked an epoch as the first single-acting engine, and the first in which economy in consumption of gas was realised as a consequence of better expansion. It was, however, large for the power generated, noisy and irregular in action, and the very rapid ascent of the piston caused so much vibration, that it could only be used for small powers.

Fig. 8.—Otto and Langen Vertical Engine—Transverse Section. 1866.

Otto and Langen, two Pistons.—In the patent taken out by Otto and Langen in 1863 the principles they intended to work upon were set forth. They proposed to construct an engine with a vertical cylinder open at the top, containing two pistons and piston-rods, one above the other. By having two pistons it was intended to break the force of the explosions, for the idea had not yet been abandoned that the shock was injurious to the efficiency of the engine. The two pistons being at the bottom of the cylinder, the momentum of the flywheel raised the upper piston and rod, which were hollow. The force of the explosion then drove up the lower solid piston through the other, the air in the cylinder being forced out through valves at

the top of the hollow piston; both pistons descended together in the vacuum formed below them. This design presented various difficulties, and the inventors soon relinquished it, and exhibited for the first time at the Paris Exhibition of 1867 their well-known atmospheric engine.

Otto and Langen, Single-Piston Atmospheric Engine.—Fig. 8 gives a sectional elevation of this engine. A is the long vertical cylinder, surrounded at the bottom with a water jacket, and open at the top to the atmosphere. P, the piston, is shown almost at the end of the down stroke. C is the rack in lieu of a piston-rod, gearing into the toothed wheel T on the main shaft K. The slide valve S, worked by an eccentric, O, admits the gas and air, which are ignited by a flame in the slide valve cover, and also discharges the products into the exhaust pipe. There are two eccentrics side by side, O and B; both are connected to the auxiliary shaft M during the down stroke, but run loose on the up stroke of the piston. In the same way the wheel T, which is also free of the shaft during the up stroke, becomes wedged to it by an ingenious clutch arrangement as the piston descends. The action of the Otto and Langen engine necessitates the use of three special mechanisms, the friction coupling or clutch gear, on the outer wheel T of the main shaft, the device for lifting the piston to admit a fresh charge, served by eccentric B, and the valve motion driven by eccentric O.

The violence of the explosion in a free piston engine is so great, that much care is necessary to make the clutch act freely and instantaneously. At the moment when the movement of the piston is reversed, the whole energy of the engine being stored up in it, the least recoil might result in an accident. This was one reason why the Barsanti and Matteucci engine failed; the ratchet and pawl were not sufficiently prompt in action. The clutch gear of the Otto and Langen engine, shown at Fig. 9, was the result of careful study, and formed one of the most ingenious parts of the engine. Upon the main shaft K there is a circular disc, *a*, which is solidly keyed to it, and carries on its outer edge at *e* four steel wedge-shaped slips or projections. The inner rim of the outer toothed wheel T is hollowed out in four places at regular intervals, just below the bolts *d*, and corresponding to the steel wedges *e* upon the disc *a*. In each of the grooves thus formed are three small cylindrical rollers. The main shaft K revolves always in the direction of the hands of a clock. When the piston flies up with the force of the explosion, and drives round the toothed wheel T in the opposite direction, the rollers run loose in the open space in the wider part of the hollows, and no pressure being exerted on the wedges *e*, the connection between the main shaft K and the rack, piston, and outer toothed wheel T is severed. The piston having reached the end of the up stroke, begins rapidly to descend (motor stroke), the motion

of T is reversed, and it also revolves in the same direction as the motor shaft. The rollers are driven forward into the narrowest part of the space, and wedged against the steel slips *e*, which grip the solid disc *a*, and the whole mass from T to K is driven round in the direction of the descending piston. The cooling of the gases below the piston forms a vacuum, but this is counteracted near the end of the stroke by the opening of the exhaust. Slight compression of the gases of combustion takes place at the bottom of the cylinder, and the motion of the piston is slackened. The toothed wheel T, therefore, revolves more slowly than the main shaft and disc *a*; the rollers run back, and loosen their grip of the wedges, and before the piston has reached the end of the stroke, the motor shaft is again disconnected.

The working of the eccentrics driving the slide valve S is also shown at Fig. 9. The valve is somewhat similar in principle to

Fig. 9.—Otto and Langen Engine. 1866.

Hugon's flame ignition valve, but more simple, as only one ignition per up stroke or per revolution is required. There is one main port, *i*, Fig. 8, leading to the cylinder, and just above it are two small openings, *h* and *j*, for admitting the gas and air. In its lowest position the slide valve port forms a communication between *i* and the atmosphere, the exhaust outlet in the valve cover being closed by a flap valve, which is lifted only when the pressure in the cylinder is greater than the atmosphere—that is, when the piston has nearly reached the bottom of its stroke. The products of combustion being thus discharged, the slide S worked by the eccentric O begins to rise, and the piston with it, lifted by the other eccentric B; gas and air enter through *j*, *h*, in the proportions of 9 to 1, mix and pass through to the cavity *m*. Communication is now made between *m* and the outer per-

manent flame *f*, and the mixture of gas and air is ignited. The upward progress of the valve shuts off the flame at *f*, and the burning gases being brought opposite the main port *i* rush into the cylinder, explode, and drive up the piston.

The movement of the two eccentrics O and B is given by the auxiliary shaft M, on which is fixed a ratchet wheel, W. The eccentrics are set to each other at an angle of 90°, and run loose on the shaft, except at certain times. Eccentric O carries the rod working the slide valve S, B has a bell crank, *r*, working on a pivot, and a lever, N. Another lever, L, has a projection, *u*, which, during the greater part of the stroke, presses against *r* and pushes it up, so that it does not catch in the ratchet wheel W of the shaft M. During the down-stroke of the piston a projection, *s*, upon the rack C, strikes the lever L and holds it down, *r* is released and catching into the ratchet wheel on the shaft M causes the two eccentrics to be carried round with it. The slide valve has been stationary during this time, with the exhaust port open to the cylinder. The flap on the slide cover which usually closes it has been lifted by the pressure of the gases, and they are discharged during the down stroke. Meanwhile the piston having reached the bottom of the stroke comes to a stand, because the rack is no longer

Fig. 9a.—Otto and Langen Engine—Plan. 1866.

geared to the wheel T. The lever N on the other eccentric B, after revolving with the shaft M, is brought round, and catching under the projection *s* on the rack, lifts it and the piston. The slide valve raised by eccentric O admits and ignites a fresh charge. The up stroke releases the lever L from *s*, the projection *u* pushing against *r* once more disengages it from the shaft M, and the two eccentrics, being no longer connected to it, are brought to a stand. Fig. 9*a* shows a plan of the engine.

This description will explain the method of ignition adopted in the Otto and Langen engine. The gases being ignited at low pressure, the ignition by flame, as in all non-compressing engines, worked satisfactorily. The speed was regulated by a ball governor, not shown in the drawing. If the speed of the engine exceeded the proper limits, the governor, by means of a pawl and ratchet, disconnected the levers working the slide valve and piston, and no charge was admitted until the speed was reduced. Thus the number of explosion strokes, instead of the strength of the charge, was diminished. This method worked more economically than direct action of the governor upon the gas admission. It was found that to reduce the proportion of gas impoverished the mixture, the explosion sometimes missed fire, and a certain quantity of unburnt gas passed through the cylinder. A third method of checking the speed was to connect the governor with the opening for the exhaust. By reducing its section, the counter pressure of the gases in the cylinder checked the down stroke of the piston, and therefore diminished the number of strokes per minute.

As the engine was single-acting, working open to the atmosphere, the heat generated was not so great as in the earlier motors. The number of strokes per minute being relatively small, the cylinder was kept comparatively cool. It was not difficult to start the engine, a few turns of the flywheel being sufficient to draw in the charge, and cause it to ignite.

A peculiarity of the Otto and Langen engine is that the number of piston strokes and revolutions of the crank are independent of each other. In an experiment on an engine of this type by Meidinger, the number of revolutions of the crank shaft varied from 40 to 106, and the strokes per minute from 20 to 43. At full power Mr. Clerk reckons the normal number of piston strokes at 30, and of revolutions at 90 per minute.

Another curious feature in this engine is that the action of the walls, which has so injurious an effect in most engines, by carrying off the heat, is here of positive use. During the up stroke the walls, by rapidly cooling the expanding gases, assist in forming the vacuum, while in the down stroke they carry off the heat, and retard the increase of pressure below the piston.

A number of experiments have been made upon the Otto and Langen engine. Of these the best known is Tresca's trial at the Paris Exhibition, 1867, on a half H.P. engine, lasting half an hour. The number of revolutions per minute was 81; the consumption of Paris gas, not including that used for the burner, was 44 cubic feet per I.H.P. per hour. Tresca estimates that only about 17 per cent. of the total heat was carried off in the cooling water. Another series of experiments, extending over several weeks, was made in 1868 by Meidinger on an engine of the same size. It ran at 75 revolutions per minute, a speed

which Meidinger found to give the best results. The gas consumption per H.P. per hour varied from 49 to 29 cubic feet; the temperature of the exhaust gases was found to decrease with the number of piston strokes per minute. In these trials an experiment was made, by allowing the governor to act sometimes upon the gas admission, sometimes upon the exhaust valve. In both cases the amount of work performed, and the number of revolutions was the same; but when the gas supply was cut off by the governor, the piston made twice as many and much shorter strokes, and the gas consumption was two-sevenths more. Meidinger also utilised these experiments to test the value of ignition at the dead point, and found that it not only prevented shock to the engine, and increased the number of expansions, but also augmented the speed. In an atmospheric engine this increase of speed was valuable, because it principally affected

Fig 10.—Otto and Langen Engine—Indicator Diagram (Clerk). 1866.

the speed of the up stroke, and hence gave a more rapid expansion. Mr. D. Clerk also made experiments upon a 2 H.P. Otto and Langen engine, the diagram of which is given in Fig. 10. The consumption of Oldham gas was at the rate of 36 cubic feet per brake H.P., and 24·6 cubic feet per I.H.P. per hour. There were 28 ignitions per minute.

The great defect of the Otto and Langen engine was its noisy and unsteady action, due to the rack and wheel, and the excessive vibration and recoil. Several efforts were made in the course of the next few years to improve upon it, though the working principle remained the same.

Gilles.—In 1874 an engine was brought out at Cologne by Gilles, the chief novelty of which was the introduction of two pistons, to avoid the noise and recoil of the Otto and Langen motor. The pistons worked vertically one above the other in the same cylinder, closed at the top, and open at the bottom to the atmosphere; the lower was the motor, and the upper the free piston. At starting, the two pistons were together in the middle of the cylinder. By the energy of the flywheel, the

motor piston being at its upper dead point was driven down, uncovered the port for admission of gas and air at the side, and the charge entered between the two pistons. The free piston was also forced down by air admitted through a valve at the top of the cylinder, until it was checked. The slide valve, through which the charge had entered, was next raised by a cam worked from the main shaft, cut off the admission, and brought the mixture opposite an external firing flame. Explosion followed, and the force drove up the free piston to its full height, the air above it escaping through holes in the cylinder cover. Meanwhile the lower or working piston was forced down through its lowest point, and driven up by the pressure of the atmosphere into the vacuum formed between the two pistons by the cooling of the gases. The upper free piston having reached its highest position, it was arrested, and not allowed to descend, till a second cam on the main shaft moved a lever, and set it free. The products of combustion between the pistons were driven out through a discharge port in the centre of the cylinder.

The Gilles engine was constructed by the firm of Humboldt & Cie., at Kalk, near Cologne, and in England by Messrs. Simon, of Nottingham, who exhibited it at the Paris Exhibition in 1878. The catch arrangement for arresting the upper piston was always a weak point, but before improvements for remedying this and other defects had been introduced, the engine was superseded by the Otto. Two drawings of it will be found in Schöttler.

An extremely useful little engine was introduced by Alexis de Bisschop, and also exhibited at Paris in 1878. Patents dated 1870, 1872, 1874. It resembles an atmospheric engine in principle, but the piston is not free; this engine will be found described in the modern part of this work.

Hallewell. — In England a patent for a kind of vertical double-acting atmospheric engine was taken out by Hallewell in August, 1875. Like Gilles, Hallewell aimed at overcoming the defects of the Otto and Langen engine, and this he proposed to do by the use of two cylinders, one single- and the other double-acting. A lever raised the piston of the first single-acting cylinder to admit a charge; explosion followed, and the piston was driven freely up to the top of the cylinder, where a discharge valve opened. It then descended in the vacuum formed below it by the cooling of the gases, and communication was opened between the vacuum and the valve-box of the second double-acting cylinder. In this cylinder air was admitted alternately on either face of the piston, through a rotating slide valve, and with the help of the vacuum in the first cylinder, the piston was driven to and fro by atmospheric pressure. The idea was ingenious but complicated, and the engine had little success.

MM. Otto and Langen had by this time formed their business into a company at Deutz, near Cologne, and the firm was

henceforth known as the "Deutzer Gas-Motoren Fabrik." They had been working incessantly to improve their engine, but after introducing several modifications, they finally abandoned altogether the idea of a free piston. At the Paris Exhibition of 1878 they brought out the celebrated Otto engine, described in Chapter vii., which rapidly superseded all others, and created a revolution in the construction of gas motors. At the same Exhibition two other engines made their appearance which, although neither of them permanently successful, presented several novel and interesting features.

Brayton.—This American gas engine had already been introduced by Brayton at Philadelphia in 1873. Owing to the peculiar method of igniting the gases, difficulties were soon experienced, which induced the inventor to substitute petroleum for gas. A full description of his later engine will be found in Part II., Petroleum Motors. In 1878 Messrs. Simon, of Nottingham, obtained Brayton's gas engine patent, and brought out the motor in England. As in the Otto, the charge was compressed, but otherwise this engine differed from all earlier types, and illustrated the principle of ignition at constant pressure, instead of at constant volume. After compression in a separate pump, the gas and air were delivered into the motor cylinder, but they were not admitted cold and then ignited and exploded, according to the usual cycle of operations. A small flame in direct communication with the cylinder was kept constantly alight, and kindled the gases as they passed it. Thus they were gradually ignited, and entering as flame, drove the piston forward, not by the pressure of explosion, but of combustion. The heat was imparted to the gas at constant pressure—that is, the piston moved as soon as the flames began to enter the cylinder, but there was no sudden explosion. A wire gauze was fixed behind the light, to prevent the flame from striking back into the compression cylinder. This method of ignition worked well as long as the wire gauze remained intact, but it was liable to burn into holes, and if the gases found their way back through any aperture, an explosion followed, and the light was extinguished. On this account Brayton abandoned the use of gas in his engine, and substituted petroleum vapour.

Simon.—To this gas engine Messrs. Simon added a small boiler above the cylinder, the water in which was evaporated by the heat from the exhaust gases. The engine* was vertical and single-acting. The steam injected into the motor cylinder increased the expansive force of the gases, and helped to lubricate the piston. This idea was not a novelty. It had been tried by Hugon, but neither his engine nor the Simon was practically improved by it. The increased bulk added to the cost of construction, and the steam was found to have an injurious effect, and to cool the contents of the cylinder too much. On

* Partly founded on Mr. Beechey's designs.

this point Professor Schöttler pertinently asks—"Whether it can be considered an advantage, since the gas engine is expressly designed to avoid the defects and dangers of a steam boiler, to add the latter to it? For small motors at least, the question must decidedly be answered in the negative." Although the theoretical principle of the Simon engine was excellent, it did not succeed. It was first shown, like the Brayton, at the Paris Exhibition of 1878.

Fig. 11.—Simon Vertical Engine. 1877.

Fig. 11 gives a section of the engine; a description will explain the method of working. A is the motor, B the pump cylinder, and K the crank shaft. Gas and air are admitted by the slide valve S_1 at the top of the pump cylinder, and drawn in through the valve *a* at the down stroke of the piston; the up stroke compresses and drives them through another valve *b* into the receiver *c*. From here they pass into the motor cylinder A, through the slide valve S; *j* is a gas jet burning continually in front of a wire gauze, at which the gases are ignited in their passage, and by their expansion drive down the piston P. The exhaust is worked by the slide valve *d*, driven from the main shaft. The products of combustion are led through the coiled tubes *e* in the small boiler F, before discharging into the atmosphere. As soon as some of the water in the boiler is evaporated by the heat of the exhaust gases, the steam passes through the pipe *f* and slide valve S into the motor cylinder. A small cam, *h*, on the governor G acts upon the slide valve S_1 for admitting the gas and air, and

cuts off the admission entirely, as soon as the speed of the engine becomes too great; this is shown in Fig. 11.

Several experiments have been made upon the Brayton and Simon engines. In 1873 Professor Thurston tested a Brayton engine in America, of 5 nominal H.P., and found that the maximum pressure in the cylinder was about 75 lbs. per square inch at the beginning of the stroke, decreasing to 66 lbs. at the cut off. The H.P. indicated 8·62, brake power 3·98, and consumption of gas 32 cubic feet per I.H.P. per hour. According to Mr. Clerk the power used for driving the pump, which causes the actual horse-power to be less than half the indicated, ought not to be included in estimating the consumption of gas. Deducting this, he calculates the expenditure at 55·2 cubic feet per H.P. per hour. Another experiment made by Mr. M'Mutrie, of Boston, showed a maximum pressure in the cylinder of 68 lbs. per square inch, the piston speed was 180 feet per minute, and the total power developed 9 H.P., the friction and other resistance amounting to nearly 5 H.P. Fig. 12 shows the diagram of this trial. In an experiment made upon a Simon engine of 7·7 I.H.P., 2 H.P. were required for the pump, and the total gas consumption was 50 cubic feet per brake H.P. per hour. The diagram of a Simon engine at Fig. 13 was taken by Dr. Slaby.

Fig. 12.—Brayton Gas Engine—Indicator Diagram.

Fig. 13.—Simon Engine—Indicator Diagram.

The engine was brought out in Germany by the firm of Otto Hennig & Cie. of Berlin, by whom several improvements were introduced, patented by Hambruch. As in the original engine the flame was sometimes blown out by the pressure of the gas, it was protected by a small cap and cover, and the burner made in the shape of a cock, with a handle to lift it out and relight it, if extinguished. In the larger engines, the ignition flame was fed from a separate small gas pump. Another improvement was to replace the exhaust and admission slide valves of the Simon engine by lift valves. The admission valve was opened by a tappet working in a socket on the main crank shaft. If the speed was too great, the governor at the end of the crank shaft drew the socket to one side, and the tappet missed it partially or altogether. Air entered the admission valve from below, gas was admitted through small holes in the seat of the valve, as in the Clerk engine, and a thorough mixing of the two was thus

attained. There was also an ingenious arrangement for equalising the pressure in the pump and motor cylinders. The admission valve, being very heavy, did not lift until the pump piston was halfway through the up stroke. A small piston above it worked in a pipe connected to the motor cylinder, and a hole in the motor piston fitted over the opening of the pipe during the down stroke. As soon as communication was established, and the pressure in the two cylinders equalised, the admission valve fell back upon its seat, and remained closed until the next up stroke.

Ravel Rotatory Engine.—Another interesting engine, two varieties of which were shown at the Paris Exhibition of 1878, was the French "Moteur Ravel." The first type was double-acting and rotatory, and was called by the inventor "an engine with variable centre of gravity." The cylinder turned upon a transverse axis, and had two heavy pistons joined together by a bar of iron, without piston-rod or connecting-rod. Gas and air were first admitted and compressed in two small pumps worked from the crank shaft, and the charge introduced alternately at either end—that is, at the top and bottom of the motor cylinder, as long as it retained a vertical position. By the explosion at the bottom of the cylinder both pistons were forced up together to the top, to be driven down again by the explosion of the compressed charge from the other pump cylinder. The motor pistons being very heavy, their motion altered the centre of gravity, and caused the cylinder, while oscillating, to turn round on its axis. The crank shaft in the centre was made to rotate by the movement of the pistons and cylinder, the piston speed being independent of the number of revolutions. The extreme delicacy of adjustment required in this engine caused it to be superseded by others; the consumption of gas was said to be about 35 cubic feet per H.P. per hour. Two drawings of the Ravel rotatory motor will be found in *Schöttler*, p. 36.

Ravel Oscillating Engine.—Another vertical oscillating single-acting type of the same engine was brought out by M. Ravel, and more favourably received in France. In this motor the piston-rod was directly connected to the crank shaft. The vertical cylinder oscillated on a centre at its lowest part. The force of the explosion drove up the piston and crank shaft, causing the cylinder to oscillate and the crank shaft to rotate. The piston descended by the impetus of the flywheel, and the shaft having completed its revolution, the cylinder returned to its original position. The action was very similar to that of an oscillating steam engine. Gas and air were admitted at atmospheric pressure through a slide valve, worked by a cam on the main shaft, oscillating with the cylinder. Ignition was effected by an external flame in the ordinary manner. There was no

special exhaust valve, but the exhaust port was uncovered periodically by the oscillation of the cylinder. Gas entered through a pipe in the slide valve, moving to and fro in the valve cover, which opened by degrees to admit an increasingly rich charge; thus the mixture finally admitted nearest the flame contained most gas, and was more easily ignited. The governor acted by throttling the supply of gas. This engine was said, like the last, to consume 35 cubic feet of gas per H.P. per hour, but it is doubtful whether so low a consumption could be obtained in a gas engine working without compression.

Foulis.—The horizontal engine patented by Foulis of Glasgow in 1878, an improved type of which was brought out in 1881, resembled the Simon in principle, and contained a motor cylinder and pump. The object aimed at by the inventor was to cause combustion to take place in the motor cylinder, at about the same pressure as that in the pump. This was obtained by adjusting the angle of the crank-pin working the pump, and proportioning the dimensions of the latter to those of the motor cylinder. In theory the engine was excellent. The hot gases, after being compressed in a pump, were forced through layers of wire gauze and an annular orifice into the combustion chamber, lined with non-conducting material, and kept at a red heat which sufficed to ignite the charge. From here they passed at constant pressure and in a state of flame into the motor cylinder. Admission was cut off at one-third of the stroke. Before being allowed to escape, the gases of combustion were made to circulate round tubes of fire-clay behind the combustion chamber, which were intended to act as a regenerator. The fresh charge passed through them immediately after, and some of the heat of the exhaust gases was thus utilised, but these and other details presented so many difficulties that the construction of the engine was afterwards given up. To raise the temperature of the incoming charge in a gas engine by means of the exhaust heat is an important problem, which inventors have hitherto been unable to solve successfully.

CHAPTER VI.

HISTORY OF THE GAS ENGINE—(*Continued*).

CONTENTS.—Engines—Clerk—Beck—Wittig and Hees—Seraine—Sturgeon—Martini—Tangye—Victoria—Economic—Bénier and Lamart—Forest—Ewins and Newman—François—Warchalowski—Noël—Durand—Mire—Baldwin.

IN a history of the development of the gas engine it is important to study, not only modern working motors, but those engines

which, although no longer made, are good in design and principle, and, therefore, deserve attention. During the last twenty years many motors have been brought out, excellent in theory and often in workmanship, which have not permanently succeeded only because they were found to infringe previous patents, or were superseded by more practical types. As none of these engines date earlier than 1878, they will not be presented in historical sequence, but, as far as possible, in the order of their importance. From henceforth it will no longer be necessary to distinguish between single-acting and double-acting engines. The double-acting type of motor, in which the charge was introduced alternately at either end of the closed cylinder, was abandoned after the failure of the Hugon, for reasons already given. Since that period no engines of this kind have, to the author's knowledge, been constructed, with the exception of the Griffin and one French motor. All others are single-acting, or admit the charge at one end only of the cylinder.

With the advent of the Otto gas engine, a new era began. Until the appearance of this motor in 1876, not one of the many engines produced had utilised the cycle of operations indicated, many years before, as the best and most economical by Beau de Rochas. Neither invention nor practical application were wanting, and as none had proved a real success, we may at least assume that their failure was due partly to the neglect of this cycle. It is Otto's special merit that he was skilful enough to put the principles of the French *savant* into working operation, and the success of his engine proved their value. It had, however, defects, which in a few years began to be generally recognised. As in all other gas engines, expansion was not complete, and the gases were discharged at a relatively high temperature and pressure. The engine had only one explosion and one motor stroke in four—that is, three strokes out of every four of which the cycle consisted, were spent in negative, and one in positive work.

Clerk.—It was to remedy the second of these defects that Mr. Dugald Clerk applied himself, in the important engine he produced and first exhibited in 1880. This motor, which is certainly one of the best brought out in England, was made by Messrs. Thomson, Sterne & Co., of Glasgow. Its distinguishing feature was that an explosion at every revolution was obtained. Of the four operations of the cycle, Clerk proposed to transfer the first only, admission, to an auxiliary cylinder, which he called the displacer. The gas and air being drawn into the displacer were slightly compressed, and delivered into the working cylinder. Here they drove out before them the products of combustion. The motor piston in returning compressed this charge into a chamber at the further end of the cylinder. It was then fired and drove the piston forward, the displacer piston

taking in a fresh charge of gas and air. The exhaust ports were in the front part of the cylinder, and the piston as it moved out uncovered them, and acted as an exhaust valve. The discharge of the exhaust gases constitutes another fundamental difference between the Otto and the Clerk engines. Otto considered that the presence of a certain quantity of unburnt gases, by retarding the progress of combustion, contributed to the efficiency of his engine. Clerk held that this residuum of unconsumed gas was highly injurious to the fresh charge, which it diluted and rendered more difficult to ignite. He was of opinion that if the motor cylinder were previously cleansed, as

Fig. 14.—Clerk Engine—Sectional Elevation. 1880.

far as possible, of the products of combustion, a weaker mixture might be used for the charge, and more perfect ignition and greater economy obtained.

Figs. 14 and 15 give a sectional elevation and plan of the Clerk engine. A is the motor cylinder with piston P, B is the displacer cylinder with piston D, which is set on the crank at an angle of 90° in advance of the motor piston, G is the conical compression space at the back of cylinder A. There are two automatic lift valves, shown at Fig 14, H, from which the gas and air pass through the pipe W (Fig. 15) into the displacer cylinder, and F, which is raised to admit the charge under slight pressure into cylinder A. Both the valves are provided with

"quieting pistons," to prevent any noise or shock. The ignition slide valve S has a flame *o* which is continually relit from the permanent Bunsen burner at *b*. Near the front of the motor cylinder are the two exhaust ports E_1 and E_2, uncovered by the piston P when it reaches the end of its stroke, and from whence the gases of combustion pass into the discharge pipe E.

The action of the engine is as follows:—The piston D of the displacer moves out, and draws in a charge of gas and air through H. The seat of this valve is pierced with holes to admit gas from the supply pipe, the forward movement of the displacer piston lifts the valve, the air enters from chamber R below, and mixes thoroughly with the gas penetrating through the holes. The number and size of the holes, in proportion to the lifting area of the valve, regulate the supply of gas, and therefore the richness of the mixture. The air valve H falls back on its seat by its own weight, but the gas supply is cut off before the piston D has quite reached the end of its stroke. The

Fig. 15.—Clerk Engine—Sectional Plan. 1880.

last part, therefore, of the charge in the displacer cylinder, first expelled as the piston begins to return, is pure air. Meanwhile the out stroke of the motor piston has begun, at an angle of 90° behind that of the displacer, and near the end of the stroke the exhaust ports E_1 and E_2 are uncovered. The pressure inside the motor cylinder is immediately reduced to that of the atmosphere. The displacer piston has already nearly completed its return stroke, and the slight pressure exerted on the charge is sufficient to lift the automatic valve F, and to admit the gas and air into the conical chamber G, at the end of the motor cylinder. As the motor piston passes over the exhaust ports, the fresh charge entering from the cool displacer, and immediately expanded by the heat of the motor cylinder, drives out the products of combustion before it. Mr. Clerk admits that a small part of the fresh charge escapes with them, but as, owing to the arrangement of the admission valves, this is mostly pure air, the cylinder is swept clean, and there is very little actual waste of unburnt

gas. The motor piston in returning first covers the exhaust ports, the valve F is instantly closed by a spring, and admission from the pump cylinder cut off. The mixture is then compressed into the chamber G, while the displacer piston begins the out stroke, and takes in a fresh charge.

Ignition follows by a flame in the slide valve S. The method adopted, shown in Fig. 15, but more clearly in Fig. 16, differs from that used in engines having only one motor stroke in four, because an ignition is required at every stroke. With the high pressure of the gases, and the great number of explosions, sometimes nearly 300 per minute, the slide would soon become red-hot, unless special precautions were taken to prevent it. The small combustion chamber or cavity 1, Fig. 16, in slide valve S, has two openings. On one side it communicates with the Bunsen burner *b* through the port 2, on the other by port 3 with the outer air, or with the explosion port of the cylinder, according to the position of the slide. A small portion of the compressed mixture is admitted from the explosion port 5, through an opening 4, into a grooved hollow in the slide valve, and is carried round to the cavity or chamber 1, which it enters behind a grating 7, intended to prevent the flame from striking back into the hollow. At 8 is shown the pin in the slide regulating the supply of gas to the grating. At the moment when port 2 of the cavity is open to the Bunsen jet burning against the face of the valve, port 3 communicates through 6 with the outer air. The gases ignite gradually as they enter the cavity through the grating, the products of combustion discharging into the atmosphere, and the gases being fed with air through port 6. As the slide moves up, carrying the burning mixture, port 2 is closed and the flame cut off, and port 3 is brought opposite the cylinder explosion port. The current feeding the flame in the cavity is so regulated, that the pressure of the ignited gases is less than that in the motor cylinder; hence the charge is easily fired. Explosion follows at the inner dead point, the piston is driven forward, the displacer takes in a fresh charge, and the cycle is repeated.

Fig. 16.—Clerk Engine—Ignition Valve. 1880.

Great care has been taken in this engine to proportion the volume of the two cylinders, to prevent the escape of any considerable part of the incoming charge with the exhaust gases. The

volume of cylinder B is almost exactly equal to that of cylinder A, deducting the compression space G, and the exhaust ports covered by the piston. But as the gases expand in consequence of the slight pressure in cylinder B, and the heat of the walls in cylinder A, their volume is increased by one-third. The mixture originally admitted is in the proportion of 1 part of gas to 8 of air. To avoid the discharge of any of the fresh gases, a small part of the products of combustion remains in the cylinder; this mixes with the fresh charge, and is estimated by Mr. Clerk as one-tenth of the total volume. The composition of the actual charge will, therefore, be 1 of gas to 10 of air and products.

Clerk Governor.—The governor in the Clerk engine is simple. Between the upper and lower lifting valves for admitting the charge to the motor and displacer cylinders is a gridiron slide. While the engine is working under normal conditions, this is kept open during the charging stroke by a spring and lever, worked from the slide valve S; but if the speed becomes too great, the balls of the governor moving out raise a lever, which catches into the lever moving the gridiron valve, and lifts it. The valve is drawn forward and closed, and the admission of gas and air wholly cut off. The two pistons continue working, but compress and discharge only the products of combustion, until the speed is reduced, and the levers lowered. This method of regulating by a gridiron slide was the invention of Mr. Garrett, of Messrs. Sterne's Works. Above each cylinder is a small oil reservoir, with an adjustable screw admitting so many drops per minute.

For starting, a special apparatus was designed by Mr. Clerk in 1883. The pipe through which the gases pass from the displacer to the motor cylinder can be made to communicate with a small reservoir, and a supply of gas and air forced into it, while the engine is running. The reservoir, charged with the mixture compressed to 60 lbs. per square inch, is closed with a stop valve, and can be kept air-tight for weeks. To start the engine, the crank is brought round to the inner dead point, the displacer piston being set at a quarter of its stroke. Communication is then established between the two cylinders and the reservoir, and the burner lit. The compressed air is thus admitted to both cylinders, and drives back the displacer piston to take in a charge, and the motor to uncover the exhaust ports. It is usually sufficient to open the starting valve once or twice, but the reservoir contains enough to start the engine six times.

Tests and experiments on the Clerk engine have been made by the inventor and the makers. The engines varied from 2 H.P. to 12 H.P., and the number of revolutions from 212 to 132. With the 2 H.P. engine the average pressure in the cylinder was 43·2 lbs. per square inch, and the consumption of gas per I.H.P. per hour 29·8 cubic feet; in the 4 H.P. the average pressure was

63·9 lbs. and the gas consumption 24·19 cubic feet. The 6 H.P. engine (Diagram, Fig 17) gave an average pressure of 53·2 lbs. per square inch, with 24·3 cubic feet of gas consumption ; in the 8 H.P. the pressure was 60·3 lbs. and a gas consumption of 20·94 cubic feet, while in the larger 12 H.P. engine, the diagram of

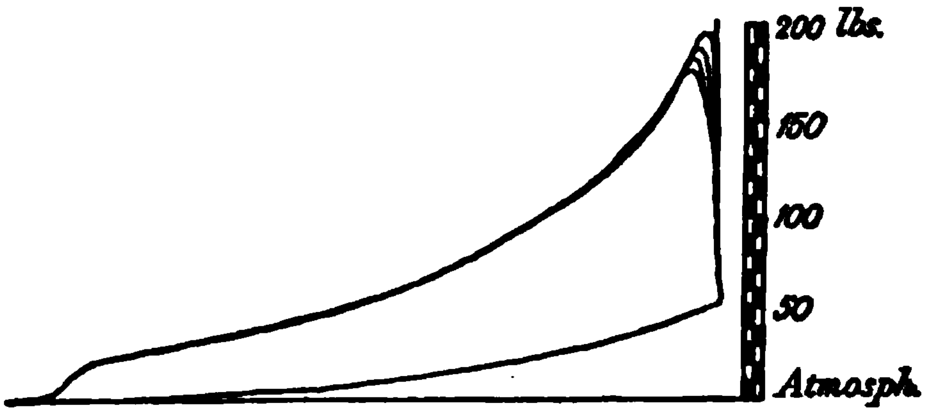


Fig. 17.—Clerk 6 H.P. Engine—Indicator Diagram.

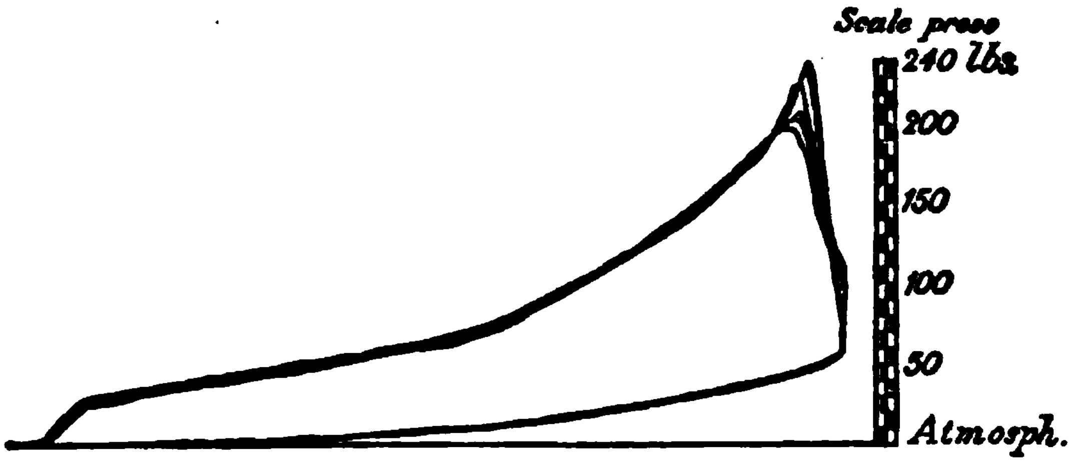


Fig. 18.—Clerk 12 H.P. Indicator Diagram.

which is shown at Fig. 18, the gas consumption was 20·39 cubic feet, with an average pressure of 64·8 lbs. It will be observed that the consumption of gas diminishes in proportion as the size, power, and pressure increase. The Glasgow gas used was very rich, and of high heating value.

The foregoing sketch of the Clerk engine shows that, though good in theory and practice, it did not completely overcome the defect of the Otto and many other gas engines, the want of sufficient expansion. As the exhaust ports opened when the motor piston had passed through three quarters of its stroke, expansion was necessarily limited. This was a disadvantage, but the engine was good in other respects, and more economical in working than previous motors, and its withdrawal from the market is to be regretted. Mr. Clerk calculates the efficiency indicated by the diagrams as 16 per cent. of the total heat received, a very creditable result at the time.

Beck Six-Cycle Type.—The Beck engine is the first example of a new cycle of operations. It belongs neither to the original double-acting two-cycle type, giving an explosion every revolution, nor to the four-cycle type of Beau de Rochas, but is known as a six-cycle engine. In other words, there is an explosion every sixth stroke, or the piston makes three forward and three

return strokes for three revolutions of the crank. The object of thus lengthening the ordinary sequence of operations is to drive out more completely the products of combustion by introducing, between every explosion and motor stroke, one stroke, forward and return, during which a charge of pure air is drawn in and expelled. This is called a "scavenger charge," and was first proposed by Mr. D. Clerk, who to a certain extent adopted the principle in his engine, though he did not sacrifice two strokes. Engineers are even now divided in opinion respecting the best method of disposing of the products of combustion. By Otto they were purposely retained, in order to diminish the force of the explosion, and he and others thought that there was an advantage in diluting the incoming charge with the burnt gases. At the same time it must not be forgotten, that these gases help to heat the fresh charge before explosion. Other engineers are so strongly convinced of the injurious effect of leaving behind any portion of the products of combustion that, in order thoroughly to get rid of them, they sacrifice a complete stroke. The advantage they claim in return for this diminution of power is that, the cylinder being thoroughly cleansed, the incoming charge is so pure that a much weaker mixture may be employed, and more rapid and certain explosion obtained, than when the products of combustion are allowed to remain. With only one explosion every six strokes, there is, of course, great difficulty in regulating the speed of the engine, and the cooling action on the cylinder walls of the charge of fresh air is also considerable. For these reasons the six-cycle type has found little favour, and is seldom seen out of England. It is best adapted to double-acting engines, adjusted to give an explosion every three strokes, first at one, then at the other end of the piston. With this modification it has survived to the present time; the Griffin engine is a good example.

The Beck engine was always of the original six-cycle type, single-acting, and was never constructed to give more than one explosion per six strokes. The working cycle of operations is explained by the following table:—

Revs. of Crank.				
1	First stroke, forward.	Admission of charge.	Negative stroke absorbing power.	Three revolutions per explosion (one cylinder).
	Second stroke, return.	Compression of charge.		
2	Third stroke, forward.	Ignition, explosion, expansion.	Positive (*motor*) stroke giving power.	
	Fourth stroke, return.	Discharge and exhaust.	Negative stroke absorbing power.	
3	Fifth stroke, forward.	Admission of pure air.		
	Sixth stroke, return.	Discharge of air to atmosphere.		

Except with regard to the scavenger charge of pure air, the engine resembled the Otto in many respects. Admission and ignition were effected by a slide valve not connected direct to the eccentric from the motor shaft. The slide valve was adjusted to make one-third as many revolutions as the crank shaft. The compression space was separated from the water jacket by a cylindrical layer of non-conducting materials, and the mixture was thus ignited in a chamber kept continually at a high temperature. By introducing the scavenger charge of pure air, and by adjusting the admission valves, the richest mixture, namely that containing most gas, entered the cylinder first, and the poorest mixture was retained round the ignition port. By these means it was intended to diminish the shock to the engine, and to obtain progressive explosion. An electrical governor was employed, and the intensity of the current was made to vary with the speed of the engine. According to the variation in the speed, the admission of gas was either throttled or wholly cut off. The governor was adjusted so that, by moving a weight on a lever, the speed could be diminished by 100 revolutions; thus the engine, when running empty for a short time, could be driven slower, instead of stopping altogether. As a six-cycle engine is naturally more difficult to start than a two- or four-cycle motor, this is a convenient arrangement.

Beck Trials.—A series of very careful experiments upon a 4 H.P. nominal Beck engine were made in London by Professor Kennedy, F.R.S., in February, 1888, and published. The indicated and brake power, speed, consumption of gas, and jacket water were all carefully observed in six successive trials. Two of these were made at full speed, at 206 and 212 revolutions per minute, and practically at full power, the next two at a mean speed of 166 revolutions, the fifth at 180 revolutions, with the maximum load for that speed, and the sixth with the engine running empty. The highest power developed was 8 I.H.P., with 6·3 B.H.P. The maximum pressure during the working stroke was 74·6 lbs., and at the highest

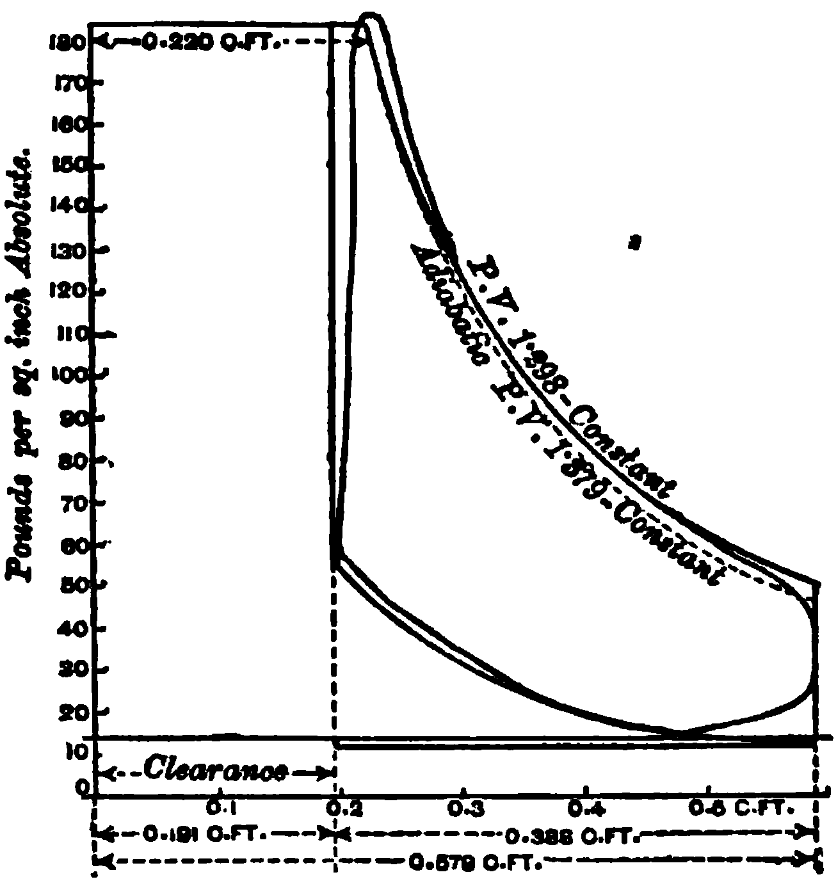


Fig. 19.—Beck Engine—Indicator Diagram. 1888.

speed there were 70·68 explosions per minute. The B.H.P. varied from 6·31, with 205·5 revolutions, to 4·84, with 169 revolutions. Taking the mean of the first four experiments, the average consumption of gas was 21·42 cubic feet per I.H.P., and 26·79 cubic feet per B.H.P. per hour. The gas used was of excellent quality, although its calorific value was not very high —viz., 611·4 thermal units per cubic foot. The proportions of the mixture were 11·5 of air to 1 of gas. One of the diagrams of the trial, No. 1, is given at Fig. 19.

Wittig & Hees.—A vertical engine, by this firm, was made for some time in Germany, and tested by Professor Schöttler in 1881. As in the Clerk engine, there is a pump and a motor cylinder, and both are enclosed in a hollow cast-iron casing filled with water, which forms the cooling jacket. The shaft is above it, and both cranks connected to the two plunger pistons are set at the same angle. This is a two-cycle engine of the usual type where compression is used. The pump piston draws in the gas and air during the up stroke, while the motor piston is driven up at the same time by the force of the explosion and expansion of the charge beneath it. In the down stroke the pump piston compresses the gases, and before the end of the stroke the pressure opens a valve in a large pipe connecting the two cylinders, and thus establishes communication between them. Meanwhile the motor piston, in descending, drives out the gases of combustion at the beginning of the down stroke through the exhaust valve, which is on the opposite side of the motor cylinder to the pump, and is worked by a cam on the main shaft. When the piston has passed through three-fifths of its stroke the exhaust closes, and the products left in the cylinder are compressed, while the pump delivers the fresh charge through the return valve. During the latter part of the down stroke, therefore, both pistons are compressing, and the incoming gas and air are thoroughly mixed with the exhaust gases. The force of the explosion then closes the return valve, and shuts off communication between the two cylinders. The ball governor acts upon the gas admission valve. The latter is usually worked

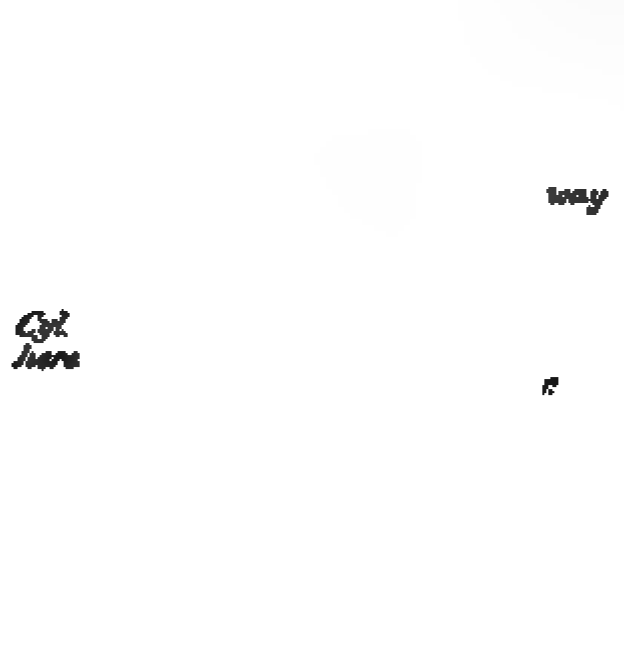


Fig 20.—Wittig & Hees Engine—Ignition Valve (Sectional Plan). 1881.

by a cam from the main shaft, which presses down the upper movable part of the valve-rod, and opens the valve. If the speed is too great, and the balls of the governor rise, a lever pushes aside the top of the valve-rod and, the cam being missed, no gas is admitted.

Ignition is effected at the lower dead point by a novel method, seen at Fig. 20, also employed in the Sombart engine. An external flame, not shown in the drawing, burns in the slide cover. When the valve is in its lowest position, the cavity *a* in the slide valve communicates with the flame and, through the small channel *b*, with the compressed charge from the valve chest *c*, while air is drawn in through an opening near the bottom of the slide valve. The mixture in cavity *a* being ignited, the valve rises, cuts off communication with the outer flame and the air, and an explosion follows as soon as *a* communicates at *c* with the fresh charge in the motor cylinder. Thus far the ignition is almost the same as in the Clerk engine. In order that the flame may be at the same pressure as the mixture in the cylinder, and the light not blown out during the upward movement of the slide by the rush of the compressed charge, there is a continuous flow of gas through *b* and the hollows *e* and *f* into the cavity. In the slide valve are two small pins opposite each other; the one is hollow, and filled with the burning gas, forming a continuation of the groove *f*. The other is conical in shape, and fits like an extinguisher over the flame, diminishing or increasing the flow of gas, according to the position of the slide.

In a 2 H.P. (nominal) engine, tested by MM. Schöttler and Brauer, the number of revolutions were 105·5, and the consumption of gas per I.H.P. per hour 39 cubic feet. In another 4 H.P. engine, tested by them at the Altona Exhibition in 1881, the number of revolutions per minute was 103, and the quantity of gas consumed was 43 cubic feet per I.H.P. per hour. Details of this experiment will be found in the table given in the Appendix.

In all the engines hitherto described, expansion of the charge during one forward stroke, or part of a stroke, of the piston was only in the same ratio as the other operations. Of the two great improvements on the original type, compression and expansion, the first, compression of the gas and air after admission, already formed a part of almost every cycle, but expansion was still imperfect. Even now, inventors have not succeeded in increasing it so as to utilise to the utmost the high pressures and temperatures obtained. Various schemes have been proposed, and various methods suggested to remedy this defect. The three following engines exhibit different attempts to obtain greater expansion, though none of them have succeeded in overcoming the initial difficulties, and in realising a good working cycle.

Seraine.—The type adopted in the Seraine, a vertical engine patented in France in 1884, was not in itself new, except as applied to gas engines. One cylinder and one piston only are used, serving the double purpose of pump and motor; the crank shaft is at the top, above the cylinder. Gas and air are admitted in the upper part, and compressed by the up stroke of the piston into a receiver below. To make this compression space smaller than the explosion space at the bottom of the cylinder, where the gases expand—that is, to increase expansion in proportion to compression, the piston-rod is of larger diameter and the stroke is lengthened, thus the area of the upper face is smaller than that of the lower. This type of piston, having a top area less than the bottom, is called a differential piston. The working of the engine is as follows:—The down stroke draws in air and gas at the top of the piston, which are compressed by the next up stroke and driven into a receiver. A slide valve worked from the main shaft now descends, shuts the exhaust and opens a passage for the compressed mixture into the lower part of the cylinder. The valve as it rises cuts off the admission, the charge at high pressure is forced into an explosion chamber in the slide valve, and ignited from a light burning in a hollow. A permanent outside flame rekindles the light when blown out. The exploded charge, striking back into the cylinder, drives up the piston, and expands during the whole motor stroke. The exhaust is not opened till the slide valve begins to descend. The gas consumption of this engine was said to be only 21 cubic feet per I.H.P. per hour. It bears a certain resemblance to a gas engine patented, but never constructed, by Sir W. Siemens; the principle of compression by the upper face of the piston will be found in several modern motors. Two drawings of the Seraine engine are given in Schöttler, p. 161.

Sturgeon.—Another much more complicated two-cylinder compression engine, the Sturgeon (Fig. 21), was shown at the Exhibition in Manchester in 1887, by Messrs. Wallwork & Co. Here the problem how to obtain greater expansion in proportion to compression was ingeniously dealt with, but at the expense of simplicity of construction. The method was similar to that used in Atkinson's first engine, which certainly resembles the Sturgeon, but the means employed were rather intricate. There are two cylinders and three pistons. The front or charging cylinder B is horizontal, and its piston *p* acts as a pump; the second or motor cylinder A is vertical behind B and has two pistons, P and P′; the four exhaust valves seen at *a* are at either end of cylinder A. The three pistons, shown in the drawing, work through their respective connecting-rods and levers upon the crank shaft; they are all trunk pistons and single-acting. The slide valves S between cylinders B and A are horizontal, in line with the crank shaft, and driven from it. As

the piston p of cylinder B moves out, it draws in the charge of gas and air through the slide valve below; in its return stroke it slightly compresses the mixture into the vertical cylinder A, and the return stroke of the other two pistons taking place at the same moment, the charge is further compressed between them. Explosion follows in cylinder A at the in stroke, and all the pistons are driven outwards and forwards, but as the pump cylinder B is shorter than the other, piston p begins to return while the motor pistons are still moving out. Hence, the charge it has taken in during the out stroke is compressed into the motor cylinder at the moment when the other pistons, near the end of their out stroke, uncover the exhaust ports, and the com-

Fig. 21.—Sturgeon Gas Engine—Sectional Elevation. 1886.

pressed charge from B helps to drive out the products of combustion. As the motor pistons begin to return the exhaust ports are shut, and all three pistons, moving simultaneously inwards, continue to compress the charge within very narrow limits. The principle of the engine is to admit the charge in the smaller, and expand it in the larger cylinder, and thus to increase the proportion of expansion to admission and compression. The engine attracted attention at the Exhibition by its noiseless working, due to the relatively large expansion space, but the number of working parts was great, and the construction was soon given up.

Martini.—A third (French) engine of the same type, the Martini, patented in 1883, was first shown at the Paris Exhibition of 1889. If made, it does not appear to have worked, but

it is interesting as presenting another development of the idea of increased expansion, afterwards practically and successfully treated by Mr. Atkinson. It is a four-cycle engine, in which admission and compression are effected during one revolution with a shorter stroke, and expansion and exhaust during the next with a longer stroke. Like the Otto, therefore, it has only one motor stroke in four. The junction of the connecting-rod and the motor shaft is effected by levers in the shape of an isosceles triangle; the point of contact describes a double curve forming two unequal circles. The larger circle is described by the crank during expansion and exhaust, and the smaller during admission and compression. The ratio, or difference in diameter of the two circles, depends on the position of this point of junction, and the length of stroke can be modified by varying the inclination of the axis of the cylinder to the axis of the motor shaft. The double circle described by the connecting-rod at the point of junction is not symmetrical with the axis of the cylinder, but so deviates that the piston approaches the explosion end of the cylinder more nearly during compression than during exhaust. The automatic ignition is effected in the ordinary way by an external flame. The admission and exhaust valves are worked by levers from the main shaft. Drawings of this curious engine are given in M. Richard's* book. M. Martini, whose works are at Frauenfield in Switzerland, now constructs four-cycle engines, both gas and oil, of the ordinary Otto type (see p. 190).

Tangye.—A compact and handy horizontal motor, embodying several of the improvements already described, and resembling in certain respects the Clerk and Seraine engines, was constructed formerly by Messrs. Tangye of Birmingham, after Robson's patent. There is one cylinder closed at both ends, and the piston-rod works through a stuffing-box. Explosion takes place at the back end of the cylinder, furthest from the crank, and with the help of an auxiliary chamber, an impulse every revolution is obtained. At the crank end the charge is admitted at atmospheric, and passed on at slightly increased pressure into an auxiliary chamber, from which it is drawn in at the other end of the cylinder, and compressed, ignited, and expanded. The openings for the exhaust are at the crank end. The engine works as follows:—On the crank face of the piston the return stroke admits the mixture of gas and air, and the forward (expansion) stroke compresses it into the auxiliary chamber at a pressure of 5 lbs. above atmosphere. At the end of this out stroke the piston overruns the exhaust ports and reduces the pressure in the cylinder below atmosphere. The slight pressure of the charge in the receiver is sufficient to lift an automatic valve, forming the communication between it and the back part of the motor cylinder. A fresh charge enters and

* *Les Moteurs à Gaz.* Par G. Richard, Paris.

drives out the products of combustion. The return stroke compresses this charge at the front end of the piston, ignition at the dead point follows, and the force of the explosion again drives the piston forward. Thus one revolution completes the whole working cycle, and by storing up the pressure in an intermediate receiver, and utilising both faces of the piston, one explosion per revolution is obtained. This is an interesting little engine, but probably uneconomical, since the gases must be discharged at too high a pressure and temperature, and a portion of the fresh charge apparently escapes with them. A drawing is given by Clerk.* The makers have now adopted the usual Otto type, as described in the modern section.

Victoria.—The "Victoria" engine, manufactured at Chemnitz in Germany, was shown at the Munich Exhibition in 1888. In this motor the cylinder is placed vertically on a box-shaped base, carrying the bearings for the crank shaft below. The base is divided horizontally into two parts. Through holes in the upper part the outer air to dilute the charge is drawn, and led by a pipe to the admission valves; the exhaust gases are carried into the lower part and there discharged. The piston and cylinder above the crank shaft are very long, and the top of the cylinder forms a guide. Explosion takes place below the piston, driving it up, and the motion is transmitted to the crank shaft through a crosshead and two connecting-rods. The admission and exhaust valves on opposite sides of the cylinder are worked by the same cam on the crank shaft through levers. The gas pipe surrounds the admission valve-rod, and gas and air are admitted simultaneously. The governor acts by interrupting communication between the gas valve and the levers and cam. The gases are ignited by a flame through a hollow tube, on the same principle as in the Koerting engine; this ignition tube is worked from another cam on the crank shaft. All the valves are held on their seats by springs. A drawing is given by Schöttler.

Three small gas motors, none of them exceeding 1 H.P., were brought out abroad about ten years ago, though they do not appear to have found their way into England. In all of them the charge was introduced at atmospheric pressure. It was difficult, without infringing the Otto patent, to produce single cylinder engines using compression. For small powers, therefore, compression and the resulting economy not being of so much importance as simplicity, the easier method of firing the charge without previous compression was preferred. As the temperature in the cylinder was thus reduced, a water jacket, in two of these engines, was dispensed with. The cylinders were ribbed externally to afford a larger cooling surface, and in this and other respects they resembled the Bisschop.

* Clerk, *The Gas Engine*, p. 196.

Economic.—The first was a vertical half H.P. engine, called the "Economic" motor, introduced into Europe in 1883 by a Company of the same name in New York. The external surface of the cylinder is ribbed, and the connecting-rod and piston, from which the crank shaft is worked, are attached to a beam. A small crank, driven from the main shaft, works a piston valve, which uncovers the valves admitting gas and air, and the opening to the exhaust. The motor piston draws a charge of gas and air into the cylinder through this valve. It is then ignited and an explosion occurs, as soon as the working piston has passed a platinum disc, maintained at a red heat by an external flame. The governing of the engine is ingenious, but complicated. On the opposite side to the cylinder is an air pump worked from the beam. Part of the air thus compressed is used to feed the ignition flame, but if the speed increases, and a larger quantity of air is introduced, it presses down a disc, cutting off the supply of gas. This method was afterwards given up, and the governor allowed to act directly on the gas valve. A drawing of the engine will be found in Witz's work.*

Bénier and Lamart.—The Bénier and Lamart was another small vertical non-compression motor, introduced in 1882, which was said to combine simplicity and compactness with good working conditions. The engine stands on a strong cast-iron base, and all the parts are brought as closely together as possible. To economise space, the crank shaft is placed alongside the cylinder, and the movement is transmitted vertically upwards from the piston-rod through a beam and connecting-rod; the stroke of the piston and diameter of circle described by the crank are about in the proportions of two to one. The cylinder is closed at the top, where admission takes place, and open at the bottom. Gas and air enter through a slide valve worked by a cam on the main shaft, and held back by springs. As soon as a series of holes in the slide are covered by another series in the valve face, the out stroke of the piston draws in the gas and air. The mixture is ignited by a flame carried in a cavity of the slide, and lit after each explosion by an external light; the exhaust on the opposite side of the cylinder is worked by a separate cam. Thus during the first half of the down motor stroke, the charge of gas and air is drawn in, explosion and expansion occupy the second half, and the return stroke drives out the products of combustion. The cylinder is water-jacketed in the ordinary way. In another and apparently an earlier horizontal type of this engine, described with drawings by Schöttler, cylindrical air tubes, open above and below, are carried through the jacket to keep the water cool. The gas consumption of this engine is said to be 49 cubic feet per I.H.P.

* *Traité Théorique et Pratique des Moteurs à Gaz.* Par Aimé Witz. Paris, 1892.

per hour. A description of the Bénier air engine will be found in Part III., and his modern gas engine at p. 162.

Forest.—The Forest engine, brought out in France in 1883, differs very little from the Bénier, except in one respect. Instead of a water jacket, the external portion of the cylinder is surrounded with deep ribs in the form of a screw, giving a large air-cooling surface. The cylinder is horizontal, and the charge is admitted and ignited at the front end nearest the crank. Power is transmitted from the piston by a lever and connecting-rod to the crank shaft. Gas and air are admitted in the same way as in the Bénier, through openings in the slide and slide face, while the cover, acted upon by the governor, shuts off these openings more or less according to the speed. The ignition and exhaust are also regulated by this slide valve, placed alongside the cylinder; it is worked by a cam on the shaft, and held back by a spring. A projection in the side of the cylinder, opposite the slide valve, causes the mixture to pass in a zig-zag direction before the ignition opening. Here it is ignited when the piston has travelled through one-third of the stroke; an outside flame periodically rekindles the gas jet. Thus admission is effected when the slide valve is at one end, and ignition when it is at the other end of its stroke; when in its central position the gases are discharged into the exhaust. The consumption of gas is about the same as in the Bénier. Drawings of the Forest engine are given by Schöttler and Witz. A much more important type of this motor, driven by petroleum, with reversible action, and intended especially for marine use, is described in Part II. It is to this class of engine that M. Forest has more particularly devoted himself.

Ewins and Newman.—Another small non-compressing single cylinder horizontal engine, brought out in 1882 by Ewins and Newman, is distinguished by its somewhat peculiar method of ignition. By the forward stroke of the piston, gas and air are drawn into a mixing chamber at the back of the horizontal cylinder, from which the chamber is separated by a flap valve. The charge is ignited by an outer flame, as soon as a slit in a notched revolving disc, worked by a catch from the crank shaft, is brought to face a similar opening at the back of the cylinder opposite the flame. The exhaust valve is also opened by the main shaft, and the return stroke expels the products of combustion. The engine is evidently constructed to run at a greater speed than is usual with such small motors.

François.—The François, a vertical engine brought out in France in 1879, bears a strong resemblance to the Bisschop. As in the latter, the explosion of the charge is utilised to force up the piston, and the atmospheric pressure to drive it down. The crank shaft is not in the same line with the axis of the cylinder, and the piston works upon it by means of two connecting-rods,

two cranks, and two flywheels. Gas and air are admitted, ignited and discharged at the bottom of the cylinder. There are two slide valves, one within the other. The larger one, containing the openings for the exhaust and the igniting flame is hollow, and held against the side of the cylinder by the slide cover and lateral cheeks. The smaller valve is solid, and there is a space between the two, varying with their position. Both valves work to a certain extent independently of each other. As the smaller moves, gas and air are admitted from the cover through the openings left between the valves, and pass to the cylinder.

Warchalowski.—All these small engines belonged to the older non-compressing types, but an interesting little compression engine, designed by Warchalowski in 1884, and made by Hörde & Co., of Vienna, was shown at the Antwerp Exhibition in 1885. It was compact and carefully designed, and differed very slightly from the Otto. The vertical cylinder was at the top. The governor regulated the supply of gas, by means of a projection, acting on the admission valve for a longer or shorter time, according to the speed.

Noël.—Several small engines obtained a certain reputation in France, and a few are still made. One of the best is the Noël, brought out in 1888, and shown at the Paris Exhibition in 1889. As in the "Economic" motor, there is one cylinder, kept cool externally by radiating ribs. In one type the piston works horizontally, and drives the main shaft below it through a beam and crank. The admission and distribution valves are simple lift valves, instead of the ordinary slide valves. They are driven by an auxiliary shaft, geared 1 to 2 from the main shaft. Air is drawn in automatically from the base of the engine, and ignition is obtained by the electric spark, the governor when required wholly cutting off the admission of gas. Another vertical type is also made, and drawings of both are given in Witz, p. 324. The engine can be driven with carburetted air.

Durand.—The Durand, a four-cycle horizontal engine, also exhibited at Paris in 1889, is adapted for working either with gas or carburetted air, and the inventor proposes to drive it with gas when small powers are required, and with carburetted air for high powers. Carburetted air is air highly charged with volatile petroleum vapour. The engine will be described among the petroleum engines, and one point only needs to be mentioned here. Ignition is by the electric spark, and M. Durand has utilised an idea first suggested in Germany. The two wires are attached, the one to a metallic point, the other to a toothed wheel, making one revolution for eight of the motor crank. The point rests against the wheel, and a spark is produced each time it slips from one

tooth to the other. By this friction of the two parts in contact, the metal is kept clean, and there is no danger of the spark failing.

Mire.—Another small engine, the Mire, made from ¼ H.P. to 2 H.P., was also brought out in 1889. Like the Clerk it has a motor and pump cylinder, and an explosion at each revolution. It is one of the very few gas engines, the action of which can be reversed, and the engine worked either backwards or forwards. This is rather a difficult operation, and gas engines are, therefore, seldom adapted for river boats. The Mire can be driven with gas or petroleum.

Two other small French engines, the Laviornery and the Étincelle, have no special distinguishing features. The first is a non-compression vertical engine, invented in 1880. The second, made by Gotendorff & Cie. of Paris, is a four-cycle horizontal compression motor, with electric ignition, and a hollow base serving as a water jacket, as in the Wittig and Hees engine. Both were exhibited in Paris in 1889.

Baldwin.—An interesting and more important engine than the two last is the "Baldwin," introduced from America in 1883. Like the Mire it is of the Clerk type. It has one horizontal cylinder divided into two parts, the back forming the motor, and the front the pump end. Gas and air enter the front, and are thence compressed into a reservoir. An automatic valve is lifted as soon as the pressure in the cylinder is reduced, and admits the compressed gases from the reservoir into the combustion chamber at the back of the cylinder, with which the chamber communicates only through a small aperture. Here the explosion takes place, and the ignited mixture enters the cylinder exactly in the centre, the smallness of the opening preventing its dilution with the products of previous combustion. This arrangement has been superseded in later engines by an apparatus called a "retarder," and the inventor maintains that none of the fresh charge escapes with the exhaust gases. Ignition is effected by the electric current, from a small dynamo driven from the main shaft. To generate the spark at starting, there is a second pulley to the dynamo, smaller in diameter, and revolving more rapidly than the ordinary driving wheel, which is used until the engine is in full work. Three different methods are employed to regulate the speed, first, by diminishing the volume of the mixture, secondly, by partial, and thirdly, by total suppression of the gas, according to the greater or less excess of speed. The ball governor acts on the admission valve; the engine is cooled by a water jacket, and works with great regularity. A drawing of the Baldwin engine is given by Witz, Vol. I., p. 254.

Various.—Other engines which scarcely outlived the time of their invention were the Lindley (1882) compound, with two

cylinders; the Northcote, in which the steam generated in the water jacket was utilised to increase the pressure; and the Laurent, employing a regenerator. Three attempts were also made, about 1883, by Fielding, Bull, and Butcher, to construct reversible engines, but without much success. Butcher further proposed to regulate the length of stroke by the governor. In the Alliaume engine the cylinder was cooled by vertical pipes in which air circulated constantly. Other engines were Linford, 1878; Funck, 1879, the first engine to use ignition by a hot tube; Maxim, 1883; and Taylor, exhibited in the English section of the Paris Exhibition of 1889.

CHAPTER VII.

THE OTTO GAS ENGINE, 1876.

CONTENTS.—Original Type—Parts—Slide Valve—Ignition—Distribution—Governor—Stratification—Tube Ignition—Modern Types—Trials—The Lanchester Self-Starter.

IT is to Otto, the celebrated German engineer, that the honour belongs of having first produced a practical working gas engine using compression, and giving an economical cycle of operations. The Otto engine was brought out at a time when, in the competition between gas and steam, the balance inclined so much in favour of the latter, that it even seemed possible that gas engines would be driven altogether from the field. The construction of the Lenoir and Hugon engines had been more or less relinquished, on account of the quantity of gas they consumed. Of all their successive imitators, none supplied the long-felt want of an engine working as steadily and economically as steam, always ready for work, where a steam engine could not be used. The Otto and Langen engine, which followed the Lenoir and Hugon, was never popular, owing to its unsteadiness, noise, and irregularity. The inventors were fully cognizant of these defects, and for years they laboured to remedy them, working on the principle of admitting the gas and air at atmospheric pressure. At length, however, to the surprise of the engineering world, they gave up altogether this method of construction, and patented in 1876 an engine, shown at the Paris Exhibition of 1878, which differed considerably from any hitherto made.

Compression.—The important innovation introduced in the Otto engine was the compression of the charge of gas and air

before ignition. The advantages of this method have been already described. Beau de Rochas had in 1862 laid down the axiom in his patent, that no gas engine could be economical, unless its cycle included compression of the mixture after admission. Yet, although the extravagant consumption in gas engines was universally admitted, no one proposed to adopt compression as a means of diminishing it, till Otto's engine appeared. Even the inventor himself did not seem to understand the radical nature of the change he introduced. He attributed the reduction in the consumption of gas and the popularity of his engines, not to compression, but to the stratification of the charge as it entered the cylinder. The novel method of admission and ignition was expressly protected in the patents. Whatever the cause, the success of this engine was from the first undoubted, and practically, for many years after it was brought out, few others were sold to any large extent. For this reason, and on account of its excellent design and workmanship, it will be useful to consider carefully the constructive details and working of the Otto engine, although it was patented as early as 1876.

Original Otto.—In this motor, the whole cycle advocated by Beau de Rochas is effected in one cylinder, in accordance with his patent. The cycle is divided between four piston strokes, two forward and two back (two revolutions), and one explosion or motor impulse is obtained for every four strokes. The original type of the engine is horizontal, and the end of the cylinder nearest the crank is open. The first stroke of the piston towards the crank (forward) draws in the charge; the second stroke (return) compresses it, and ignition follows at the inner dead point. In the third stroke (forward) the force of the explosion drives the piston, and in the fourth stroke (return) the products of combustion are discharged. The third is the only motor stroke, in which the pressure of the gases produced by explosion causes them to expand, forcing out the piston, and performing actual work. All these operations are carried out and completed at the end of the cylinder away from the crank, and on one side of the piston only.

At this working end there is a large clearance space, comprising about four-tenths of the whole volume of the cylinder, into which the charge is compressed, and where ignition takes place. As the piston does not enter this clearance, the gases of combustion can never be completely expelled, but a portion is always left in the compression space to mingle with the incoming charge. Otto considered that it was an advantage thus to retain a part of the products of combustion, to act as a cushion against the piston, and deaden the shock of the explosion. As only one motor impulse is given in four strokes, the motion for the other three must be obtained from the impetus of the moving parts. Hence the fly-wheel is made larger and heavier than usual. There is one other

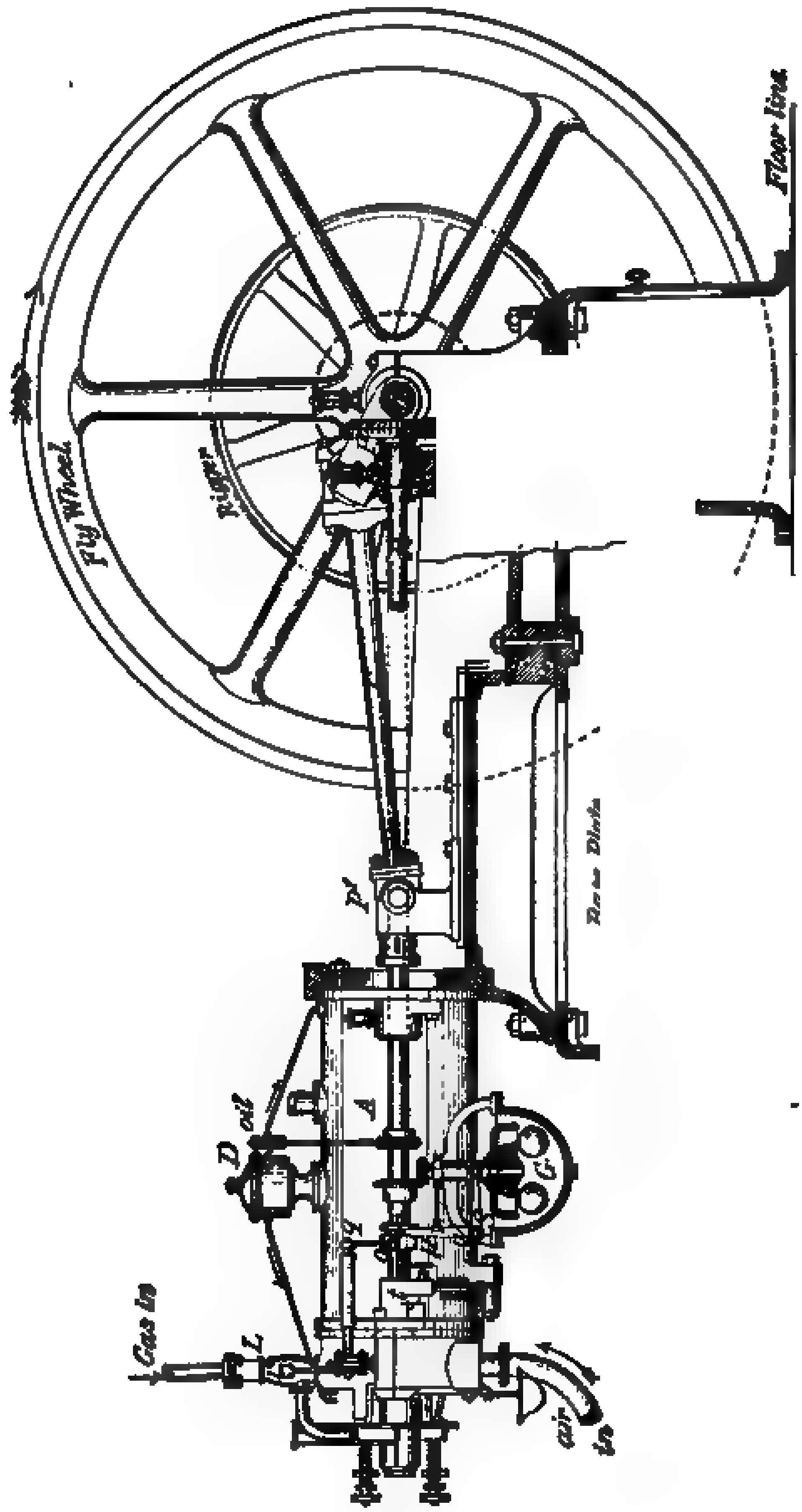


Fig. 22.—Otto Engine, 1876—Side Elevation.

peculiarity of structure to be mentioned, in studying the original Otto type. In most gas motors the charge itself is carried past

Fig. 23.—Otto Engine, 1876—Sectional Plan.

the flame, or ignited by an electric spark. Here the gas is supplied for three different purposes through separate pipes.

There is first the supply pipe, providing gas to mix with air for the charge, and controlled by the governor; another for the permanent outside flame; and lastly, a branch pipe feeding a small intermediary chamber in the slide valve, which communicates first with the outside flame, then with the compressed mixture, and fires the charge. The arrangement has been modified in the later engines.

Fig. 22 gives a side elevation, Fig. 23 a plan of an 8 H.P. motor, and Fig. 24 an end view of the Otto engine. The different parts are similarly lettered in the three drawings. A is the motor cylinder, and P the piston, shown in Fig. 23 at its furthest point in the in stroke, with the compression or clearance space behind it. At the crank end the cylinder is open. The piston-rod is keyed to the crosshead P′, to which the con-

Fig. 24.—Otto Engine—End View. 1876.

necting-rod C, working on to the crank shaft K, is also attached. R is the counter shaft, driven by the wheels E and F from the crank shaft, and revolving at half the speed of the latter. This shaft R has many functions to perform. Through a crank H and small lever I it drives the slide valve S, where the charge is admitted, ignited, and exploded. Below is the ball governor G, acting upon the gas valve L, and regulating the supply; a cam and tappet *t* upon the counter shaft open the exhaust valve *e* once in every revolution; and, lastly, a strap from it drives the oiling gear D above the cylinder, and supplies oil as long as the engine is working. The cylinder is surrounded by a water jacket W. It has two openings, *a* and *b*—*a* is the charging port, filled first with gas and air at atmospheric pressure from the distributing chamber in the slide valve, and then with part of

the compressed charge, and through this port a tongue of flame shoots into the cylinder, and explodes the remainder; *b* is the opening for the exhaust, and the gases of combustion pass out at *e*. Below at *m* is another opening through which air is admitted into the slide valve, mingles with the gas, and is carried forward until, at *a*, it enters the cylinder.

In Fig. 24 the double branching of the gas pipe to supply the permanent outside burner, and the temporary flame, is seen at B_1. The slide valve S is worked by crank H and lever I; *e* is the exhaust opened by lever *k*, and the cam *z* on the counter shaft. The governor works upon the gas valve L by a series of levers, *r*, *r′*, while a handle at *r″* regulates the admission of gas to the valve from the rubber gas bag.

Slide Valve. The slide valve of this engine is an ingenious piece of mechanism. There is first the face next the cylinder,

Fig. 25.—Otto Engine, 1876—Sectional Plan of Slide Valve.

secondly, the valve proper, and, thirdly, the cover on the outside; the latter is held against the valve by springs and screws. The slide valve alone is driven to and fro; the other parts are fixed. Fig. 25 gives a sectional plan of the three parts, and their connection with the cylinder. Here A represents the cylinder, E the slide face, S the slide valve, and D the cover. W is the water jacket, *a* the charging port introducing the mixture into the cylinder, *m* the opening in the slide face for admitting the air, which passes at *o* into a chamber in the slide valve with three openings, Q and M, and *n* opening to the slide cover. Shortly after, as the slide valve passes from right to left, the gas is admitted from L in the cover, through *n* into the chamber. Continuing its motion in the same direction, the slide next brings the opening Q of the chamber opposite *a*, and its contents are discharged into the cylinder, to be there compressed by the next back stroke of the piston.

Meanwhile, at the other end of the slide valve, a different series of operations have been taking place at the same time. At B is the permanent burner in the slide cover, open to the atmosphere. While the slide valve passes from right to left, the chamber N is brought opposite B, but as it contains no gas no ignition occurs. But as soon as it reaches *d*, gas from the third pipe is introduced into it through a grooved hollow in the cover. Before the slide valve commences its return movement, and while the mixture is being compressed in the cylinder,

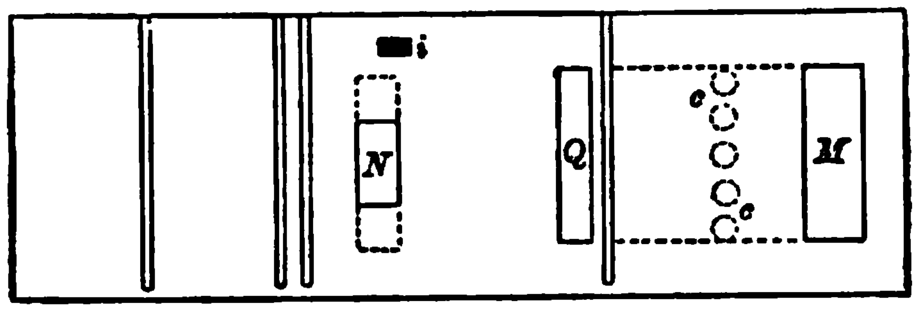


Fig. 26.—Otto Engine—Vertical View of Slide Valve.

the chamber N is filled with gas from *d*, ignites on passing before B, and when brought opposite the cylinder port *a* fires the charge. It is necessary, however, to equalise the pressure of the gas flame and of the charge, lest the flame be blown out.

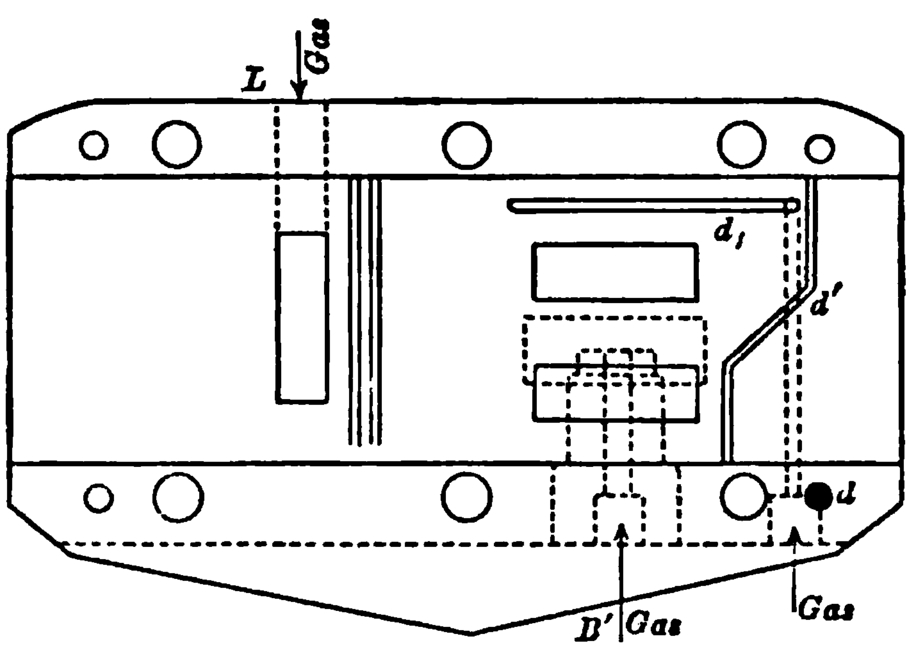


Fig. 27.—Otto Engine—Vertical View of Slide Cover. 1876.

As long as the small lighting port is in communication with the atmosphere through B the flame is easily maintained, but as the slide moves onward, and connection is cut off, it begins to fail. Therefore, before it reaches *a*, a hole is passed in the slide face, communicating through a T-shaped passage with the charging port. A small portion of the compressed charge passes through it to the flame in N, and establishes an equilibrium of pressure between the mixture in the cylinder and the flame, before the latter reaches and fires the charge.

Figs. 26 and 27 give a vertical view of the slide and slide cover. In the latter L is, as before, the pipe to admit the main

supply of gas, B_1 is the smaller gas pipe feeding the permanent flame B, Fig. 25, which burns at the bottom of a chimney. Through another small pipe the gas passes at *d*, Fig. 27, and through the grooved passage *d'* to the lighting chamber N, Fig. 26. Above this chamber is the hole at *i* through which, and a passage in the slide face, communication is established between the cylinder and the light, as soon as the slide passes the opening of the passage. At *c c*, Fig. 26, are the holes for the gas entering the admission and distribution chamber M Q. Figs. 28 and 29 show a vertical section of the slide valve and cover, with the arrangement of the ignition flame. The parts are lettered as before. N is the lighting chamber in the slide, B the

Fig. 28.—Ignition Flame and Slide Valve.

Fig. 29.—Ignition Flame and Slide Cover.

permanent burner in the slide cover. In Fig. 28 the flame at N is shown while being formed. Air enters from below, gas through the groove *d'*, corresponding with the opening *d* in the slide cover, Fig. 25, and passes through this T-shaped channel into N. The chamber being in communication with the flame burning in the chimney, the charge in it is ignited. Fig. 29 gives a view of the intermediary flame in chamber N, after it has been cut off from the outer burner, and from the gas pipe *d*. The T-shaped passage *d'* here opens on the other side into the cylinder port through *i*, and a small portion of the compressed charge passes through into N. Shortly after, the port is brought opposite the cylinder port *a* and ignition follows. Thus during one piston stroke three operations take place, and the slide valve has to form and kindle the intermediary flame, equalise the pressure between it and the charge in the cylinder, and ignite the latter.

The method by which all these various actions are timed to occur is ingenious. Fig. 30 gives a diagram of the proportional

movements of the motor crank, the counter shaft, and the slide valve. The Roman figures represent the positions of the crank, the Arabic figures those of the counter shaft, while the letters *a*, *b*, *c*, *d*, show the movement of the slide valve.

As the motor crank moves from I. to II. in the direction of the arrow, the crank on the counter shaft which is set at an angle

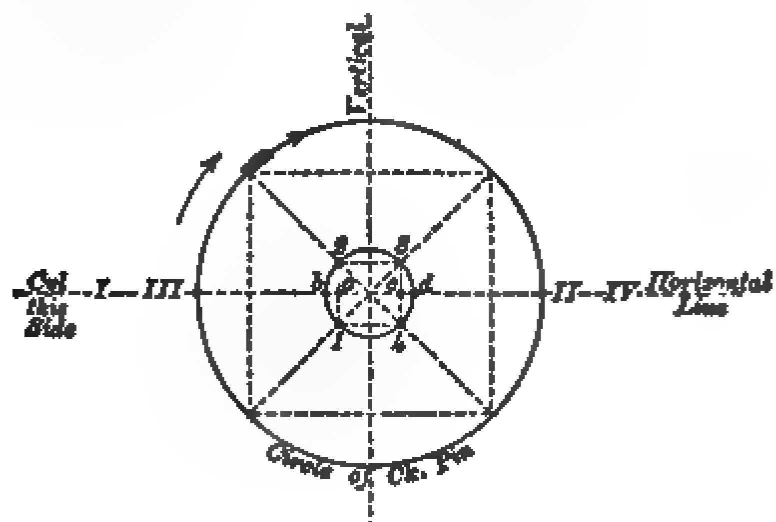


Fig. 30.—Otto Engine—Positions of Crank, Counter Shaft, and Slide Valve.

of 45° behind it passes from 1 to 2, and the slide valve moves from *a* to *b* and back again. During this time the piston moves out, and the fresh charge is drawn at atmospheric pressure into the cylinder. Fig. 31 gives this position at A. Air is admitted at *m*, gas at N, and both after mixing in chamber M Q (Fig. 25) pass through *a* into the cylinder. The next crank movement completing the first revolution is from II. to III. (Fig. 30); the

Fig. 31.—Otto Engine—Positions of Ports and Passages. 1876.

counter shaft moves from 2 to 3, the slide valve from *a* to *c*. Fig. 31, B, indicates the position of the slide valve. All the ports of the cylinder are closed, while the piston compresses the charge. The lighting chamber is brought opposite the permanent flame and fired, and through the port for equalising the pressure, part of the charge in the cylinder is also compressed into it by the return movement of the piston. Position III.

(Fig. 30) represents the inner dead point; ignition and explosion take place, and drive the piston through its second forward and only motor stroke. The crank shaft revolves from III. to IV., the counter shaft from 3 to 4, the slide valve passes from *c* to *d* and back again. Fig. 31, C, shows the progress of the slide during and after the ignition of the charge. From IV. to I. the crank completes its second revolution, the counter shaft passing from 4 to 1 concludes one revolution, and the slide valve moves from *c* to *a* and takes up position D (Fig. 31). All the admission ports are closed to the cylinder, while the products of combustion are driven out through the exhaust by the second return stroke of the piston.

By this arrangement air enters the mixing chamber M (Fig. 25), and is passed on into the cylinder, during nearly the whole of the admission stroke, but gas is only admitted during the latter part. The two ports are so proportioned that the ingress of air is first cut off, and gas enters alone at the end of the stroke. The effect of this distribution on the stratification of the charge will be discussed further on.

Fig. 32 gives a view of the exhaust valve. The lever opening it, K, shown also in Fig. 24, passes beneath the motor cylinder A, and is worked by a cam, *t*, on the counter shaft R. The end of the lever is held against the counter shaft by a spring. At a given moment the cam *t* presses one end of the lever down, and the other raises the lift valve *s'*; *b* is the opening into the cylinder, and *e* the discharge into the exhaust. When valve *s'* is raised, the action of the piston drives the products of combustion through *b* and *e*. The cam being one-quarter the circumference acts upon the valve during one-quarter of a counter shaft revolution, or one stroke of the piston. A second cam upon the other side of the shaft can also be adjusted to push down the lever, and hold open the valve, when starting the engine, during the compression as well as the exhaust stroke. This method of diminishing the pressure in the cylinder while starting has been adopted in other engines besides the Otto. The second cam is easily disconnected from the shaft, as soon as the engine is at work.

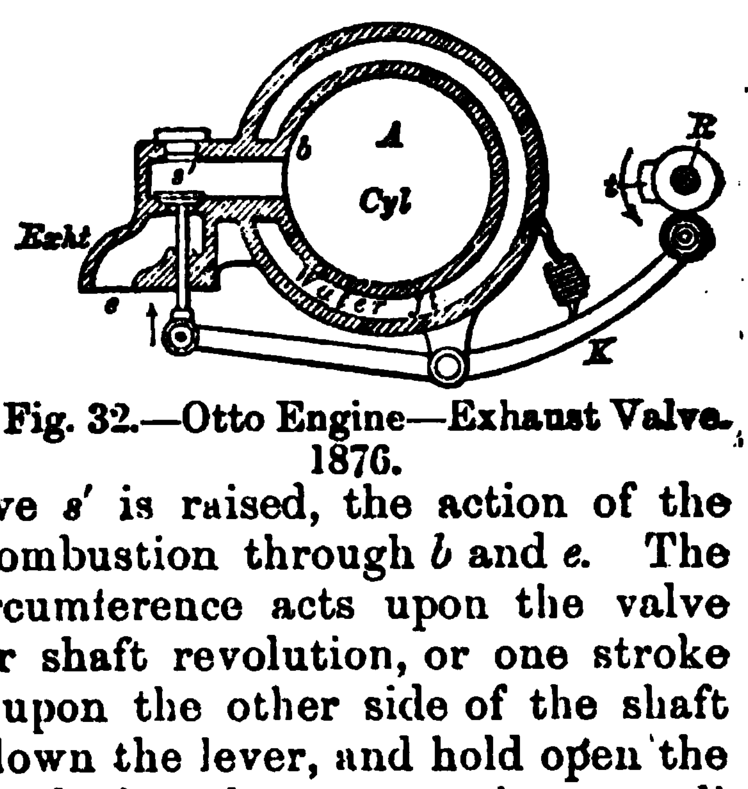
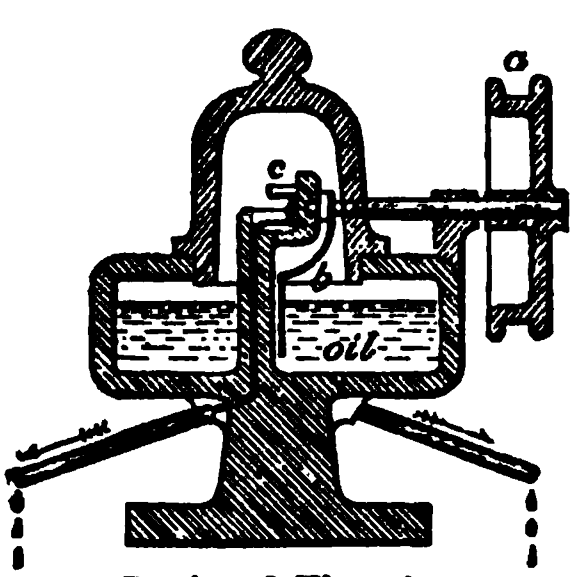


Fig. 32.—Otto Engine—Exhaust Valve. 1876.

The speed of the engine is regulated as shown in Figs. 22 and 24, pp. 76, 78. Upon the counter shaft R is a socket with a tappet *a*, having a similar action to the exhaust cam. When the shaft is revolving at ordinary speed, this tappet regularly catches and pushes up one end of the lever *q*, resting upon it, the other end of which terminates in the rod *r*, opening the gas admission

valve L. But if the speed increases, the balls fly out and push up another small lever *u*, which, forcing the socket to one side, causes the tappet *o* to miss the end of the lever *q*. Nothing but air is admitted, and no explosion follows until the speed is reduced, and the tappet being again in position acts upon the gas valve. The handle *s* (Fig. 22) is intended to raise the balls only when starting the engine, and falls back automatically after the first explosion.

Two methods were available for regulating the speed, either to cut off wholly the supply of gas, or to decrease the quantity admitted; the former was preferred as being more economical. No gas could then pass unburnt through the cylinder, but, as an explosion was missed every time the gas valve was closed by the governor, the speed became irregular. Otto was obliged, therefore, to modify the governing gear when the engine was used to drive dynamos for electric lighting, where a very steady speed is required. Instead of the tappet, a cam with various steps acted upon the lever *q*. When the speed fluctuated within slight limits, the cam opened the gas valve for a longer or shorter time, and varied the strength of the charge. The explosions were sometimes weak, sometimes strong, but never wholly missed, unless the speed was so greatly increased that the wheel of the lever slipped quite off the cam. Latterly, for small motors, Otto adopted the pendulum type of governor, which is frequently met with in modern engines. It consists of an oscillating weight at the end of a rod, swinging backwards and forwards with the motion of the engine and of the slide valve, to which it is attached. As long as the speed is normal, a horizontal rod, connected to the pendulum, fits at each revolution into the notched end of the valve-rod opening the gas valve. But if the speed and the motion of the slide valve increase, the swing of the pendulum cannot overtake them. The weight shifts the rod out of position, a miss fire occurs, and no gas is admitted until the speed of the engine is reduced.



Sectional Elevation.
Fig. 33.—Otto Gas Engine—Oiling Apparatus.

The lubrication of the Otto engine is simple and ingenious. Great care was necessary in oiling all the parts, especially the slide valve. Fig. 33 shows a vertical section of the oiling apparatus. An external view with the two lubricating pipes is shown at D, Fig. 22, p. 76. This apparatus is worked by means of a small pulley, *a*, and a strap on the counter shaft. The cup is filled with oil into which a small wire, *b*, on the same shaft as the pulley, dips at every revolution. The drop is wiped

off on a fixed pin, *c*, placed over a trough. From the trough it runs into one of the two pipes, and is carried either to the piston or the slide valve. Sometimes this arrangement is made in duplicate, and the cup divided vertically. Two kinds of oil can be then used at the same time, the better quality for lubricating the slide valve, and a coarser oil for the piston. In this apparatus the oil is kept cool, and lubrication is automatic and continuous.

For starting small power engines, the additional cam to keep the discharge valve open during compression as well as exhaust was found sufficient. But the Otto motors were soon applied to larger powers (over 20 H.P.), and it then became impossible to start them without a special apparatus. The German Otto firm often use a small, to start a larger gas engine. In the two-cylinder 30 H.P. gas motors driving the dynamos lighting the Cologne Theatre, a small 2 H.P. engine is employed to set them in motion; when once started the little engine stops.

Modern Otto.—Few engines more ingeniously constructed than the Otto have yet appeared, and the cycle has now been extensively adopted by many other firms. More than 30,000 engines were sold in the first ten years, and according to the German firm 45,000 engines, with a total of about 200,000 H.P., had, up to about 1895, been constructed by them.

Otto himself attached, as we have said, the greatest importance to his system of admitting the charge. The slide valve is so constructed that pure air enters first, and passing into the cylinder mingles with the products of combustion left from the previous charge, which the piston (as it does not enter the clearance space) cannot expel. Hence, next the piston, there is said to be a weak mixture, which is intended to deaden the shock, to retard combustion, and to take up some of the heat developed by the explosion. Gas next enters the slide valve and mixes with the air, and this layer, on reaching the cylinder, forms a dilution of medium strength, the proportions being about 7 of air to 1 of gas. Finally, by the movement of the slide valve pure gas alone, without any admixture, is admitted into the cylinder. It is this gas which, through the grooved passage in the slide valve, feeds the burning light, and causes it, as Professor Witz says, to shoot into the poorer mixture like a tongue of flame. Thus there are three strata in the cylinder, of three different degrees of richness, the mixture nearest the piston being so diluted that it will not ignite, except by the force of the explosion. The flame is supposed to leap from one layer to another, producing the slow combustion so much desired by Otto. Many eminent scientific men supported his theory of stratification, while others were

strongly opposed to it. Perhaps the best proof that it does not really take place in the manner supposed, is furnished by the makers of the Otto engine in different countries, who have abolished the slide valve, and substituted admission by lift valve.

The patents for the Otto engine, which have now expired, were formerly acquired in England by Messrs. Crossley, of Manchester; in France, by the Compagnie Française des Moteurs à Gaz; in America, by Schleicher, Schumm & Co., of Philadelphia. The German firm have long been established at Deutz, near Cologne.

Several of these firms, while adhering to the principle of the original type, have made many alterations in the working details. Messrs. Crossley have introduced ignition by a hot tube, instead of by a flame carried in the slide valve. Fig. 34 gives two views of this method of ignition, as used for many years; it has recently been again modified. C is the passage into the cylinder, T the cast-iron tube, and R the asbestos lining of the chimney. The tube is closed at the top, and kept at a red heat by a Bunsen burner, B. During the compression stroke a cam on the counter shaft lifts the lever L, and pushes up the timing valve E into the port D. No portion of the compressed charge can, therefore, enter the tube, and any burnt gases left in it escape through A into the atmosphere. At the inner dead point, when the piston has completed the compression stroke, the cam leaves the lever L free, E is drawn down by the spring S, and the compressed mixture, rushing into the red-hot tube, is there fired and ignites the charge. G and F are outlet channels for discharging the burnt gases through A. Thus a rich mixture alone enters the tube, and ignition is certain. By this method the pressure of the charge is utilised, and is made to fan the flame instead of blowing it out. Porcelain tubes are generally used in the Crossley-Otto engines, because they appear to last very much longer. Messrs. Crossley and Holt are also said to have been the first to introduce the pendulum governor, and Mr. Holt

Fig. 34.—Otto Engine—Ignition Tube.

has brought out an ingenious oiler, which lubricates according to the amount of work on the engine.

As the Otto engine became more popular, and larger sizes were made, the cost of working it with town gas was found to be heavy, especially on the Continent, where coals are generally dearer than in England. Several methods were introduced for making gas more cheaply than by distillation from coal. These will be described later on; the system most generally used is Dowson's cheap gas producer, which reduces considerably the cost of working an engine, as compared with town gas. This gas, generated on the spot, is, however, economical only when employed for larger engines. As it is much poorer than lighting gas, it requires to be diluted with a smaller proportion of air; the ratio is generally about 1 of Dowson gas to $1\frac{1}{2}$ of air.

For powers over 30 H.P., the makers of the Otto brought out engines having two cylinders side by side, and two sets of valves, driven from an auxiliary shaft placed between them. One governor regulated the speed. The two motor cranks worked on one shaft, and were 180° apart, thus giving a motor impulse alternately from each piston, for every revolution of the crank shaft. A two-cylinder engine indicating 30 H.P. was shown at the Electrical Exhibition at Frankfort in 1891. Each cylinder was complete in itself, with hot-tube ignition and admission valves, and could be worked alone. Gas was supplied from a receiver controlled by the governor, which could be disconnected from one cylinder, and made to act upon the other only, if less power was required. Messrs. Crossley have now given up the two-cylinder type, side by side, for the end to end arrangement, as shown in Fig. 35. At Chicago the Deutz firm exhibited seven gas engines from 2 to 20 B.H.P., besides oil motors. A new vertical 6 H.P. engine, driven either by gas or oil, and running at 360 revolutions per minute, was also shown. It has no timing valve or side shaft, and the exhaust only is driven by an eccentric, the other valves being automatic. A flexible membrane connected to the exhaust valve is depressed during each suction stroke, interposes a rod between the eccentric and the exhaust, and prevents the eccentric from acting during the ensuing compression stroke. Thus the exhaust remains closed. This action is suspended by the governor, if the normal speed is exceeded, and the exhaust opened twice, instead of once, every cycle. In all modern Otto engines, hot-tube ignition is used.

For large and medium powers the horizontal type of engine is always adopted. A demand, however, soon arose for small, light engines, occupying little space, and the "Domestic motor," Fig. 36, for two-man power and upwards, was brought out to meet this requirement. Being vertical, it is more compact than a horizontal engine, and can easily be transported. It has few

parts, and these are as simple as possible. A pendulum governor acts on the gas valve through a vertical rod with knife edge, catching at a given moment into a projection, which lifts the valve admitting the gas. If the speed increases, the pendulum swings back this rod, the knife edge is missed, the gas valve is not opened, and no explosion occurs. In this engine, as made

Fig. 36.—Otto-Crossley Domestic Motor.

by Messrs. Crossley, gas and air are admitted through a rotatory valve into the cylinder. In the German type, the ignition tube is not shut off by a valve, but is always open to the cylinder, and a certain quantity of the gases of combustion, therefore, remains permanently in it. The compression stroke forces this residuum and part of the fresh charge up the narrow passage

leading to the hot tube, and causes ignition. This type of motor is made in sizes up to 1½ H.P.

The Otto engine, described in detail in the beginning of this chapter, is of the original type brought out in 1876, and various modifications and improvements have since been made, especially by Messrs. Crossley. In their motors, as now constructed, the slide valve has been abolished for all sizes of engines, and air and gas are separately admitted through lift valves, worked by cams on the counter shaft. The exhaust lift valve, worked by a cam and levers, has been retained. The modern ignition by hot tube, instead of a flame in a cavity, has been described already. Communication between the cylinder and the tube is generally made through a timing valve, worked by a cam. A patent pendulum governor or a ball governor is used. The counter shaft is driven by worm gear from the crank shaft, the oiling is practically the same as that of the original type. Most

Fig. 37.—Otto-Crossley Engine for Electric Lighting. 1894.

Otto engines are provided with a safety apparatus to prevent their starting backward, and many have a special starting gear.

The type shown at Fig. 35 is constructed by Messrs. Crossley for powers from 100 to 250 I.H.P., and runs at 160 revolutions per minute, with lighting gas. A smaller horizontal single cylinder type, also for lighting gas, is made from 2½ to 64 I.H.P., and has a speed of about 180 revolutions (see Fig. 37). For electric lighting heavier flywheels are used, and the engines

are made single cylinder from ½ H.P. nom., running at 250 revolutions, up to 30 H.P. nom., making 230 revolutions per minute. Above these powers two-cylinder engines are used. Vertical motors are made from ¾ to 8 H.P. For driving hoists, pumping water or sewerage, the Crossley-Otto engines are coupled direct on one base plate.

An improvement has recently been introduced by Mr. F. W. Crossley and Mr. Atkinson (who is now with the firm), necessitating two important alterations in the engine. The exhaust pipe is lengthened to about 65 feet, and the admission of the charge is slightly modified, the air valve being opened in advance of the gas valve, and a little before the end of the motor stroke. The pressure of the gases in the cylinder combines with the speed created by the long exhaust pipe to cause a strong current of fresh air through the compression space, sweeping out the burnt products, and thus the cylinder is said to be more perfectly cleansed from the residuum of the former charge before the gas valve opens, and a fresh mixture begins to enter. This scavenging process, or air blast, is further assisted by the partial vacuum caused by the reduced pressure in the cylinder. The admission ports must be adjusted, the shape of the cylinder at the clearance end altered, and all sharp bends avoided, to facilitate the speed of the scavenger charge.

The advantages of this new method of exhaust and admission of air bid fair to make it one of the most important innovations yet introduced in 4-cycle engines, the value of which can scarcely be overrated. The purity of the fresh charge is a special gain in engines worked with Dowson or other power gas, and renders ignition more certain and regular, independently of the varying quality of the gas. The volume of cold air drawn in helps to cool the cylinder walls, and to keep the engine in good working condition for many hours. There is a considerable gain in maximum initial pressure, and the mean pressure in the cylinder is also much higher. In a test carried out by Messrs. Crossley and Atkinson in 1895, the engine, with these improvements, developed 39·9 H.P. on the brake, 46·45 I.H.P., and showed a consumption of 14·17 cubic feet of Openshaw gas per I.H.P., and 16·48 cubic feet per B.H.P. hour. It ran at 173 revolutions per minute, the mechanical efficiency was 86 per cent., and thermal efficiency 28 per cent. The heating value of the gas was taken at 640 T.U. per cubic foot. These figures are perhaps the lowest yet reached in a gas engine, and the results are specially important, considering that there are no new working parts in this modified engine.

According to Messrs. Crossley, the usual consumption of Manchester gas for driving their engines varies from 17 to 25 cubic feet per I.H.P. hour, in proportion to the size of the engine. With Dowson gas the consumption of anthracite

is from 1·0 to 1·4 lb. per I.H.P. per hour, or of coke 1·5 lb. At the Crossley Works, Dowson gas is used to furnish from 200 to 400 H.P., no steam power being employed. About 25,000 Crossley engines are said to be at work in the British Isles.

Trials.—More experiments have probably been made on the Otto than on any other gas engines. Details of these will be found in the table, but a few of the more important are here summarised. The earliest published trials on an Otto engine were carried out by MM. Brauer and Slaby, in Germany, in 1878. The engines indicated 3·2 H.P. and 6 H.P.; the first ran at 180 revolutions, the second at 159 revolutions per minute. Between 38 and 40 cubic feet of gas were used per I.H.P. per hour. This was a large consumption for an Otto engine, though at the time the economy, as compared with the expenditure in other motors, was striking. From this period for the next ten years the consumption of gas gradually diminished, as various improvements were effected in the engines. The amount of gas used also varied inversely with the size of the engine tested. In an important experiment* by Dr. Slaby in 1881 on a 4 H.P. engine, making 157 revolutions per minute, the gas consumption was 28·3 cubic feet per I.H.P. per hour. An indicator diagram of this trial is given at Fig. 38. Another, carried

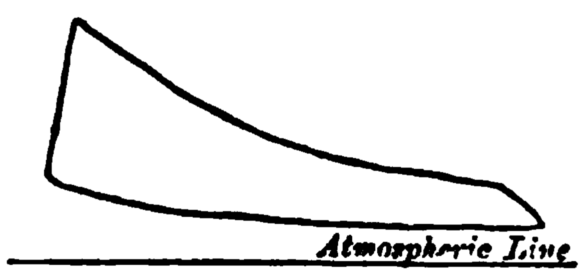


Fig. 38.—Otto—Indicator Diagram. 1881.

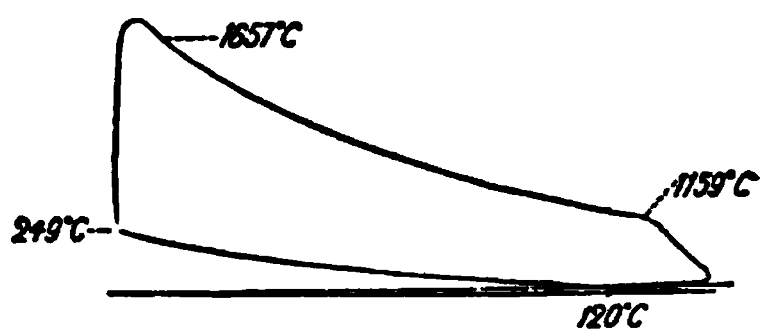


Fig. 39.—Otto—Indicator Diagram.

out in America by Messrs. Brooks & Steward, under Professor Thurston's direction (diagram Fig. 39), was on an engine giving 9·6 I.H.P.; the number of revolutions was 158, and the gas consumption per I.H.P. per hour, 24·5 cubic feet. The greatest economy appears to have been obtained in an engine tested by Garrett, of 14·26 I.H.P, consuming 19·4 cubic feet of Glasgow gas per I.H.P. per hour (diagram Fig. 40). An interesting trial is on record, made by Teichmann & Böcking in 1887 on an Otto engine of 50·8 B.H.P., using Dowson gas. The consumption was estimated at 103 cubic feet per hour per B.H.P., equivalent to one quarter that quantity, say 25 cubic feet of town gas (see

*Full details of this experiment will be found in the Appendix to Professor Fleeming Jenkin's Paper on "Gas and Caloric Engines." Lecture delivered before the Institution of Civil Engineers on 21st Feb., 1884.

Table). In 1881 a series of trials were made at the Crystal Palace by Professor Gryll Adams, on Otto engines of various powers.

In 1888 an important set of trials of motors for electric lighting was made in London, under the auspices of the Society of Arts. The judges were Dr. Hopkinson, F.R.S., Professor A. Kennedy, F.R.S., and Mr. Beauclerk Tower, and three gas engines were entered for competition, an Otto-Crossley, an Atkinson, and a Griffin. So careful and accurate a series of experiments on different gas engines at the same time and place, and under similar conditions, had not, to the writer's knowledge, been made before. The Otto engine was of 9 H.P. nominal, the Griffin of 8 H.P. nominal, and the Atkinson of 6 H.P. nominal. For the special purpose of electric lighting, the engines were tested according to efficiency under the following heads:—Regularity of speed under varying loads; power of automatically varying the speed; noiselessness; cost of construction, of maintenance, and of fuel. All three engines worked satisfactorily. The

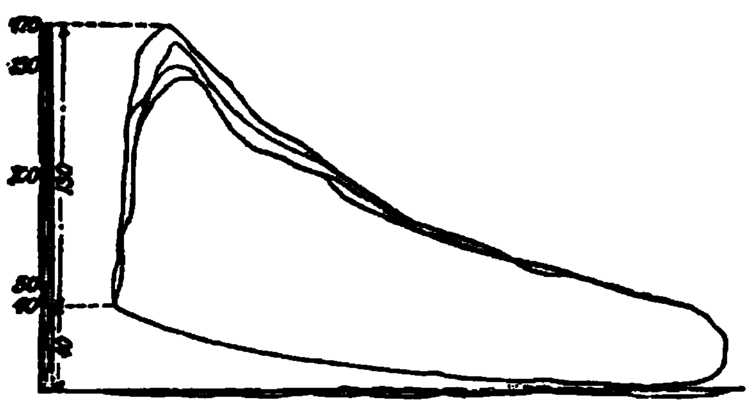


Fig. 40.—Otto—Indicator Diagram. 1887.

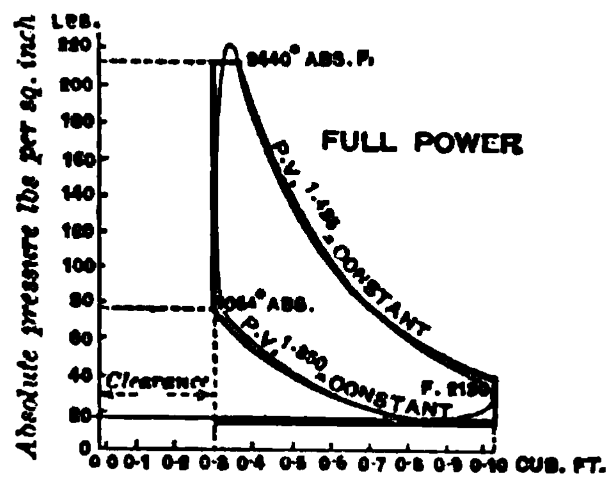


Fig. 41.—Otto—Indicator Diagram. 1888. *Soc. Arts.*

lowest consumption of gas was obtained with the Atkinson engine, although it was the smallest in size. Comparing the two other motors, the judges gave the preference to the Griffin for regularity of speed, and to the Otto for economy of gas and oil. The gas used (Gas Light and Coke Co.) was carefully analysed. The quantity of jacket water per hour was noted, as also its temperature on entering and leaving the jacket. Each of the engines was tested at full power, at half power, and running empty without load. Indicator diagrams were taken every quarter of an hour, and sometimes every five minutes. Fig. 41 gives a diagram of the Otto engine taken during the trial.

As the engines were all new, and entered for a trial competition, they were, probably, more carefully made than usual. Hence the results were perhaps rather better than those obtained with similar types of engine, under ordinary working conditions. The Otto engine used was of the modern kind, with lift valves and tube ignition. Details of the experiments will be found in the

table, but for comparison the chief results of the three engines running at full power are given below.

The same gas was used in all the trials.

TRIALS OF GAS MOTORS, SOCIETY OF ARTS, LONDON, SEPTEMBER, 1888.

Name of Engine.	Atkinson.	Otto-Crossley.	Griffin.
Diameter of cylinder, .	9·5 inches	9·5 inches	9·02 inches
Length of stroke, . .	12·43 inches	18 inches	14·0 ,,
Indicated horse-power, .	11·15	17·12	15·47
Brake horse-power, . .	9·48	14·74	12·51
Revolutions per minute, .	131·1	160·1	198·1
Mean effective pressure (from the diagrams), .	46·07 lbs.	67·9 lbs.	54·15 lbs.
Quantity of gas per I.H.P. per hour (exclusive of ignition flame), . .	18·82 cub. ft.	20·55 cub. ft.	22·64 cub. ft.
Quantity of gas per B.H.P. per hour (exclusive of ignition flame), . .	22·14 ,,	23·87 ,,	28 ,,
Explosions per minute, .	121·6	78·4	129
Indicated horse-power for driving engine alone, .	1·67	2·38	2·96
Mechanical efficiency, .	85%	86%	80%
To work engine alone, .	15%	14%	20%
Percentage of total heat of combustion turned into work, or actual heat efficiency, . .	22·8	21·2	21·1
Calorific value of 1 cub. ft. of gas, T.U. (from chemical analysis), .	633	626	624

Details of other and more modern trials will also be found in the table.

The Lanchester Patent Self-Starter is a simple but ingenious device for starting gas engines of any size. The apparatus consists of a tube through which gas is forced into the cylinder, displacing part of the air and mingling with the rest to form an explosive charge; a cock at the top of the cylinder; and a second cam on the auxiliary shaft, to open the exhaust valve during the compression, as well as the exhaust stroke. The latter now forms a part of most gas engines. The method of starting is as follows:—The piston being previously placed in position slightly over the incentre of the working stroke, gas is introduced into the cylinder through a special nozzle, and also admitted through another pipe with two branches. One terminates in an external flame, the other communicates freely with the cylinder through the cock mentioned above, in which is an automatic valve, usually held down by its own

weight or by a spring, and leaving the passage free. When the pressure in the cylinder exceeds that in the passage, the valve is driven up, and shuts off communication. The gas entering by the nozzle displaces the air in the cylinder, and forces it out through the passage until, the air being gradually expelled, gas follows and ignites at the external flame. The supply of gas being cut off, the velocity of the flame propagation exceeds that of the mixture issuing from the nozzle, the flame strikes back into the cylinder, an explosion is produced, and the piston driven out. The force of the explosion closes the automatic valve. With small engines this is sufficient to start, but in larger motors the second cam actuating the exhaust is brought into play. This apparatus is used to start the Forward, Bisschop, and other engines.

CHAPTER VIII.

THE ATKINSON ENGINE.

THE ingenious mechanism of the Otto engine described in the last chapter, and the fact that it was the first to realise the cycle of Beau de Rochas, made it long and deservedly popular. It seemed as if a gas engine had at last been produced, working with the requisite steadiness and economy. But, as time passed, the question arose whether a still lower gas consumption and better design were not possible. Experiments had proved that only about one-fifth of the heat given to the best Otto engine was utilised as power. Defective expansion was one of the chief causes of this loss of heat, and how to remedy it is the problem still occupying the minds of engineers. To increase the length of the piston-stroke enlarges the cylinder volume, and admits more of the charge, and at the same time allows greater scope for the expansion of the gases. It is the proportion of the volume of admission to the total volume, or number of expansions, which may be altered, and the piston made to travel through a shorter distance when admitting and compressing, than when expanding the charge. The solution of the problem presented by Mr. Atkinson is original and ingenious. Practically, the question is treated from a new point of view, though the method had been fore-shadowed in several directions by earlier inventors,—Seraine, Sturgeon, and Martini—but none of them had been able to realise a working success. The numerous experiments made on the Atkinson engine prove that it is also very economical, works well, and requires little attention.

Principle of Atkinson Engine.—Mr. Atkinson has introduced two engines, the main principle of which is the same, although carried out in different ways. The whole cycle is performed in one cylinder; there is one motor-stroke in four, and this stroke corresponds to one revolution of the crank only. The four operations of the Beau de Rochas cycle—admission, compression, explosion plus expansion, and exhaust, are effected in four separate strokes of different lengths, and hence the ratio of expansion is independent of the ratio of compression. A special feature of both engines is that the compression or clearance space varies according to the operations taking place in the cylinder, whether the piston be admitting, compressing, or expanding the charge. Like others who have studied the subject,

Mr. Atkinson considered that the two main sources of waste of heat were the exhaust and the water jacket, and he has attempted to reduce these losses by arranging the connection between the piston and the crank, so as to give different lengths of stroke. If the piston travels more quickly, there is less time for the heat to be carried off by the jacket; if a longer expansion stroke is obtained, the heat and pressure of the gases have more time to act in doing useful work on the piston, before the exhaust opens. The more rapid and longer expansion obtained by Atkinson, after many trials, forms the chief novelty in his engines. He claims to expand the charge to the original volume during one-eighth of a revolution, as compared with half a revolution during which it is expanded in the Otto. In the latter engine the charge is drawn in during one out stroke of the piston, or half a revolution, and expanded during the next, while the crank makes another half revolution, to the original volume,—namely the total volume of the cylinder. In the Atkinson engine, the stroke expanding the charge is nearly double as long as that admitting it, and hence the charge expands to almost twice its original volume. In a 6 H.P. motor the suction or admission stroke is about 6½ inches, the expansion stroke is about 11½ inches. As the whole cycle is effected during one revolution of the crank, this increased expansion is obtained in one-quarter revolution, and expansion to the original volume in one-eighth revolution, or one-quarter the time occupied in the Otto engine. The heat transmitted through the walls to the jacket should be in proportion—first, to the time the wall surfaces are exposed, and secondly, to the differences of temperature between them and the gases they enclose. Rapid and prolonged expansion ought, therefore, to check the waste in both directions. The quick moving out of the piston brings the ignited charge in contact with the walls for a much shorter time, and the heat being absorbed in expansion, by the time the exhaust opens the gases are comparatively cool. Mr. Atkinson maintained that he utilised three times as much heat as Otto in the same time. It is certain that, owing to the way in which the lengths of the piston strokes are proportioned, more complete expansion is obtained, but whether more heat is really utilised than in other motors, trials alone must decide.

There is no slide valve in either of the Atkinson engines. The mechanism for admitting and firing the charge is simple, but the link and lever arrangements for connecting the piston and crank are a little complicated. On the whole, both his engines work economically, and the consumption of gas in the later "Cycle" engine, as shown by the Society of Arts' trials, is very low. The modifications introduced are—I. Initial compression into a much smaller space than the original volume. II. Smaller

wall surface exposed in a given time. III. Rapid and continued expansion.

Differential Engine.—As early as 1879 Mr. Atkinson took out a patent, No. 3213, for a compression engine of the Otto type, in which ignition was obtained by a red-hot tube. This was one of the first instances of a working engine firing the gas in this way; the same method was employed in the same year

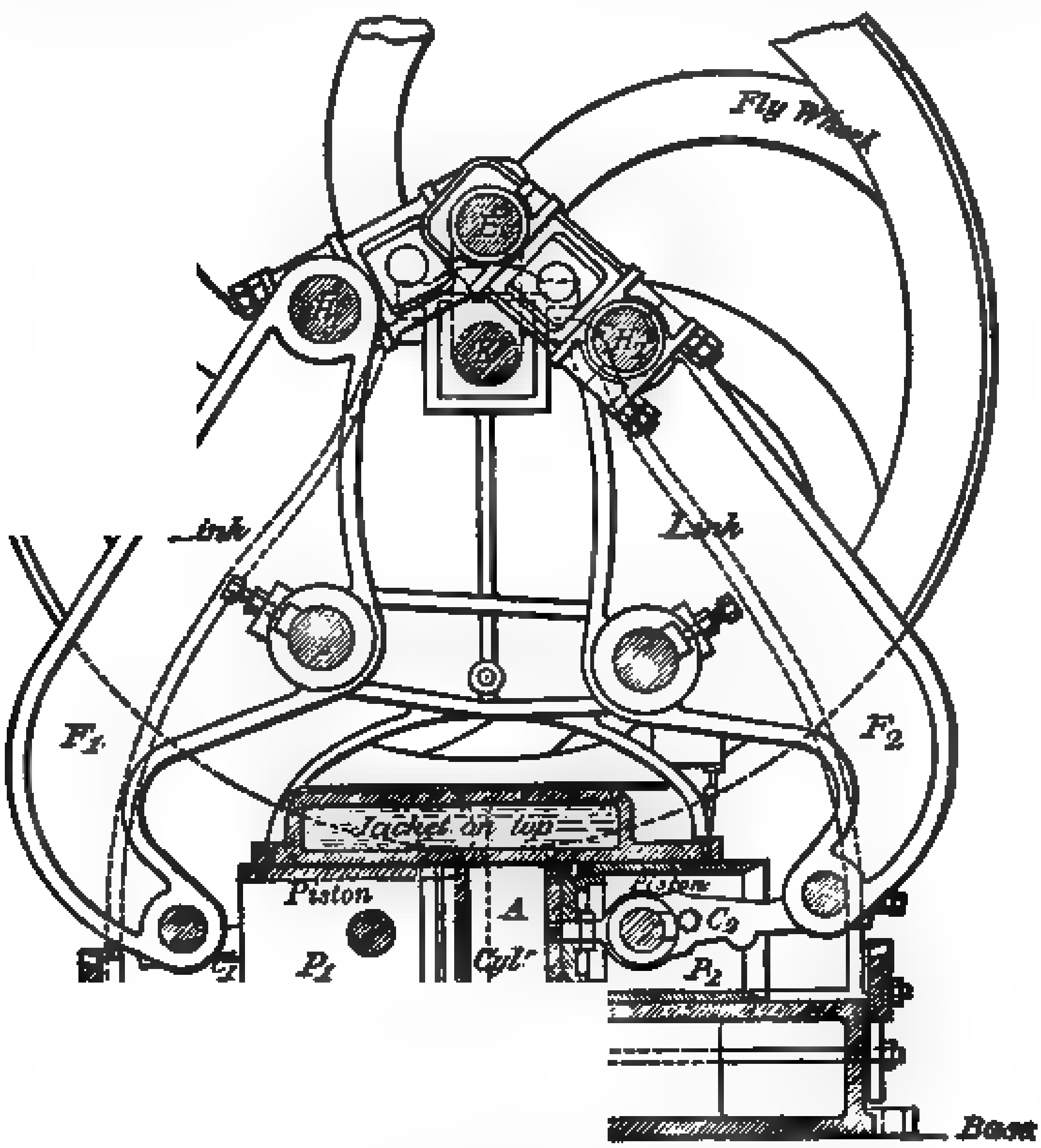


Fig. 42.—Atkinson's Differential Engine. 1884.

by Leo Funck. Atkinson soon abandoned this type of construction, and began to work on new lines. Fig. 42 gives a sectional elevation of his first or Differential engine, exhibited at the Inventions Exhibition in 1885. The horizontal motor cylinder A contains two pistons, both working outwards, and joined by their connecting-rods, C_1 and C_2, to the bent levers, F_1 and F_2, which act through H_1 H_2 upon the crank shaft K. Of these two pistons the left-hand one, P_1, may be called

the pump piston, and chiefly compresses the charge; the right-hand, P_2, is the working piston, and effects the greater part of the working stroke, but both pistons co-operate in utilising the explosive force of the gases. There is only one cylinder, open at both ends; during the compression of the charge the pistons hold the exhaust port and the ignition tube closed.

The method of admission, ignition, discharge, and regulation of the speed is simple. Air is admitted through an automatic lift valve, gas through a valve opened by a rod from an eccentric on the main shaft. The rod terminates in a knife-edge acting on the lever of the gas valve, and if the speed be too great the governor, which is driven by a pulley from the crank shaft, shifts the valve-rod out of position, and no gas is admitted. Ignition is by a tube kept at a red heat by an external Bunsen burner. It has no valve, but opens directly to the cylinder through a small aperture. The exhaust, uncovered by piston P_2 in its out stroke, is closed by an automatic valve, and opened by the action of the piston. The admission and distributing valves are in front, the exhaust is at the back of the cylinder, which has a water jacket at the top only, as seen in the drawing.

The method by which the two pistons act upon the crank is given in the four positions at Fig. 43, showing the links, the levers, and the movement of the connecting-rods. p_1 and p_2 are, as before, the pump and working pistons, and h the ignition tube. In the first position, *a*, the two pistons are shown close together, and both at one end of the cylinder. The products of combustion have been completely expelled, and the clearance space between the pistons is reduced to its smallest limits. The energy of motion in the flywheel now lifts the crank, the pump piston p_1 moves rapidly to the left, the other piston following it slowly, the automatic admission valves are uncovered at B, and the charge (position *b*) enters between the two pistons, through the openings left in the black lines in the drawing of the outline of the cylinder. In position *c* the admission valves are closed, the working piston has followed the pump piston rapidly to the further end of the cylinder, and the charge is shut into the diminished volume between them, leaving a relatively small surface of cylinder wall by which the heat can escape. A slight further movement of the pump piston uncovers the ignition tube, the compressed gases enter, the charge is fired, and the working piston moves rapidly out to the extreme limit of the cylinder, uncovering the exhaust valve. The pump piston follows more slowly, driving out the products of combustion (position *d*).

In Fig. 43 the variable clearance space is shown, and the action of the pistons upon the ignition and exhaust valves. The clearance volume is in fact formed by the movement of the pistons, and communicates at a given moment with the exhaust or with the ignition, causing the charge to be fired or expelled.

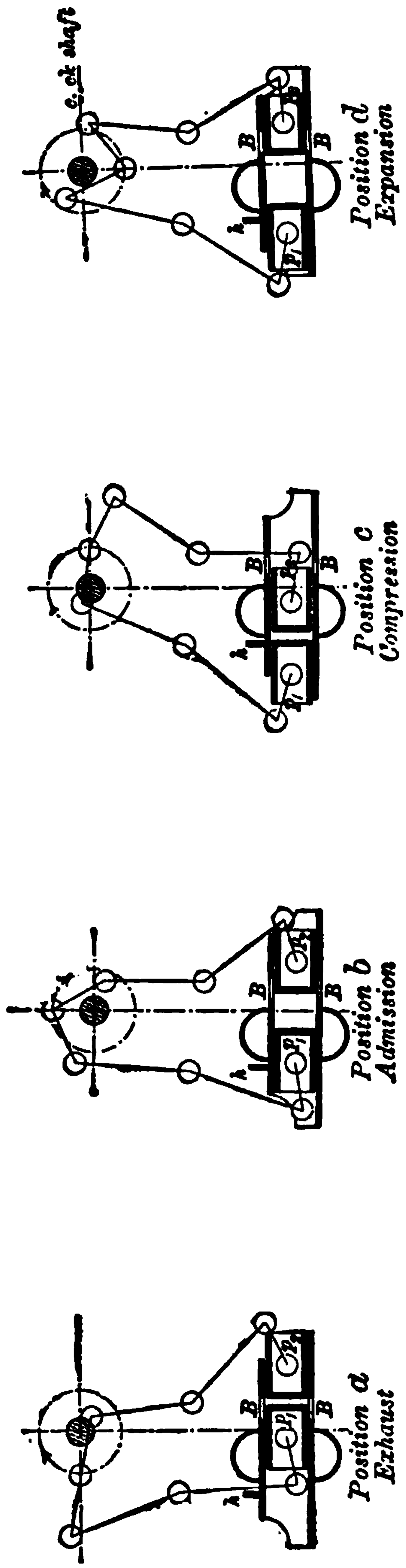


Fig. 43.—Atkinson Differential Engine—Piston and Links, Positions. 1884.

The pistons themselves act as slide valves. Between them the functions of admission, compression, expansion, and exhaust are performed in four strokes of unequal lengths. The actual clearance space, into which neither piston enters, is about 1 inch in a 2 H.P. engine. The distances between the pistons during the different operations are as follows:—Admission 3·4 inches (position *b*), Fig. 43; Compression 1·7 inch (position *c*); explosion and expansion 7·6 inches (position *d*); exhaust 1 inch (position *a*). The proportion of the two strokes, or the ratio of admission and compression to expansion and exhaust, is as 2·58 to 4·44.

In theory the action of the Differential engine appears to realise almost complete expansion, but the practical results obtained were not uniformly satisfactory. Professor Schöttler found that the consumption when running empty was very high, and the mechanism of transmission was also defective. The levers, links, and connecting-rods were rather unwieldy, and after a few years' trial of the engine, Atkinson improved upon it by the production of the "Cycle," in which the same principle was retained, embodied in a much simpler form.

"Cycle" Engine.—In outward appearance the "Cycle" engine, patent No. 3522, March 12, 1886, seems to differ little from the ordinary type of a compression gas engine. The axis of the horizontal cylinder is placed, according to the usual arrangement, at right

Fig. 44.—Atkinson Cycle Engine—Elevation. 1886.

angles to the crank shaft, the side next the crank being open, and it contains only one piston. Nevertheless, in this, as in

the Differential engine, the expansion and exhaust strokes are longer than the admission and compression strokes, and the whole cycle of operations is completed during one revolution of the crank, with one piston and cylinder, without the aid of a pump. This constitutes the novelty of the "Cycle" engine. Instead of using two pistons, the four unequal strokes are all obtained with one piston, working upon the motor crank through a series of rods, links, and levers, instead of acting through the usual connecting-rod. The admission and exhaust are operated with valves in the ordinary way. There is no valve to the ignition tube, but the charge is ignited automatically during the compression stroke.

Fig. 44 gives a sectional elevation of a 2 H.P. "Cycle" engine. A is the cylinder, P the piston, at W the water enters the jacket. The cylinder is placed upon a strong base-plate, B, in the interior of which is the mechanism for transmitting power to the crank. The engine is provided with two flywheels. E is the lever, H the small crank or vibrating link, the end of which only is seen, C is the connecting-rod, M the lever joining H to the crank shaft K, and L the fixed point in the base, about which the lever E and small crank H oscillate. The ball governor, not shown, acts upon the gas admission valve by a lever and valve rod. As long as the speed is regular, the valve opens to admit the gas. The valve rod *v* rests against it, but is not solidly connected, and if the speed be increased it is drawn back, the valve remains closed, and no gas is admitted.

The valves for admitting and discharging the gases are worked by two rods, one of which is shown at *m*, and opened by two cams on either side of the crank shaft. Except when acted upon by the cams, they are held against the end of the cylinder by a spring and connecting stirrup. The ignition tube *i*, kept at a red heat by a Bunsen burner, is permanently open to the cylinder through a very small passage, and has no timing valve to uncover it at a given moment, and ignite the gases. The ignition of the charge in this engine is based upon the theory, that a small quantity of the gases of combustion always remains in this narrow passage. The pressure of the return stroke drives these gases and a portion of the fresh compressed mixture up the red-hot part of the tube, where they ignite, and spreading back into the cylinder fire the remainder. The method works well, owing probably to the purity of the charge obtained by the long exhaust stroke, and ignition is perfectly regular. The exact moment of firing is determined by raising or lowering the chimney, and altering the position of the tube, but the time of ignition is not so precisely fixed in this as in most engines. Premature explosion during the exhaust stroke is prevented by

the low pressure of the gases of combustion. But whether ignition occurs at the inner dead point, or when the piston has moved out a little way, does not greatly affect the action of the engine. In the one case the expansion stroke is longer, in the other the pressure is higher.

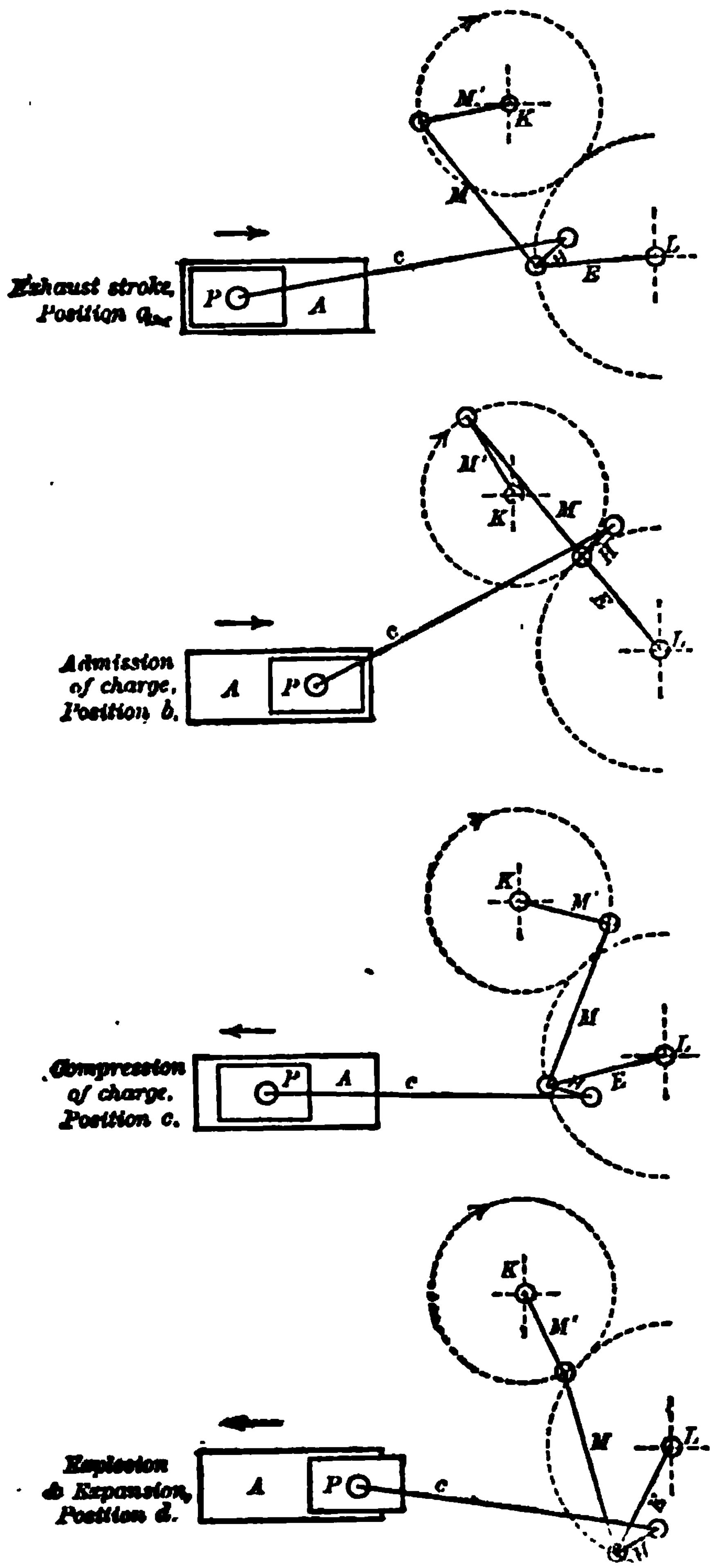


Fig. 45.—Atkinson Cycle Engine—Four positions of Link and Toggle Motion. 1886.

In these details the Atkinson engine differs little from others. Its distinguishing feature, by which practically complete expansion is said to be obtained, is the link and toggle motion shown in four positions at Fig. 45. A is the cylinder and P the piston as before. *c* is the connecting-rod to the small vibrating link H, which, through E, is joined to the fixed point L. M is the lever connecting through the crank M_1 to the crank shaft K. Position (*a*) shows the end of the exhaust stroke, when the piston is at the inner dead point. The piston moves out, drawing in the charge, and the lever M rises, carrying the link H with it. At (*b*) the crank has performed nearly a quarter of a revolution, and H and M are in their highest positions. The energy of motion carries M and M_1 round, forcing down H (position *c*) and the piston moves in, compressing the charge, but not to the point from whence it started. The clearance space left at the end of the cylinder is slightly larger than before, and the charge

is driven into it, at a pressure of about 45 lbs. The proportion of compression to admission is as 4 to 5. At the end of this stroke, when the crank has performed another quarter revolution, the pressure forces the gases up the red-hot tube, and ignition follows. The piston is driven out to the extreme limit of the cylinder, M and H are both in their lowest positions (*d*), and the crank has completed three-quarters of a revolution. The exhaust stroke following is longer than the expansion, since the piston moves in to the extreme end of the clearance space. M and H are raised, the crank completes its revolution, the products of combustion are thoroughly discharged, and the cylinder cleared for the next admission stroke. Fig. 46 shows the same

Fig. 46.—Atkinson Cycle Engine—10 Positions of Crank, &c. 1886.

arrangement for ten positions of the piston, connecting-rod, lever, and crank during one stroke. In the "Cycle" engine the ratio of the cylinder volume utilised for compression is 2·5, and for expansion, 4·3. The lengths of the four unequal piston strokes are:—First forward stroke (admission), 6·3 inches; first return stroke (compression), 5·03 inches; second forward stroke (expansion), 11·13 inches; second return stroke (exhaust), 12·43 inches. These dimensions are for an engine of 2 H.P. nominal.

The proportion of expansion to admission and compression can be varied to suit any quality of gas. By adjusting the centre L and link H, the engine is easily adapted for Dowson gas. The prolonged exhaust stroke is a source of economy.

The gases are discharged at a pressure of only 10 lbs., and the cylinder being thoroughly cleansed after each explosion, ignition is said to be more certain. The usual strength of the charge is 8 parts of air to 1 of town gas. Sometimes the dilution is 6 to 1, but the mixture is richer than in the Otto engine, as the charge is free from the products of former combustion. Experiments lately made by Mr. Atkinson, to determine the effect on the

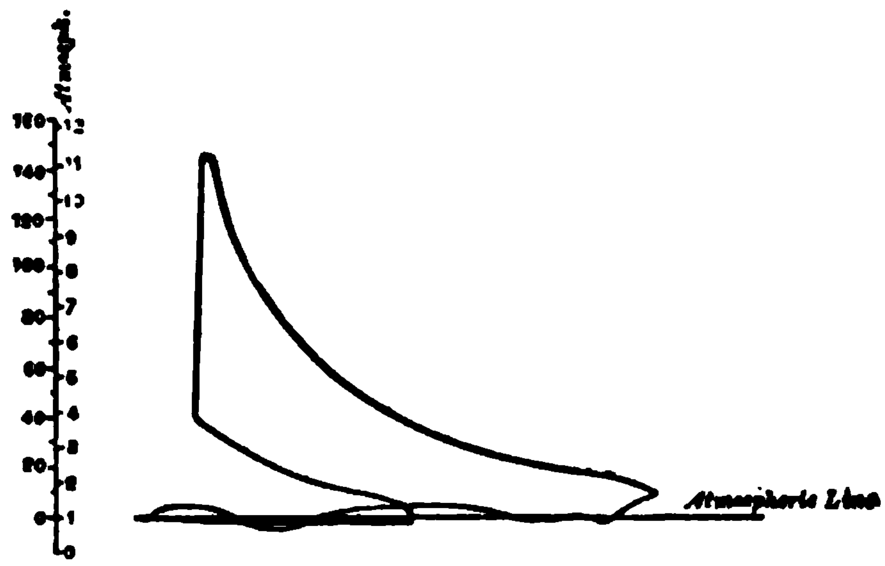


Fig. 47.—Atkinson Cycle Engine—Indicator Diagram.

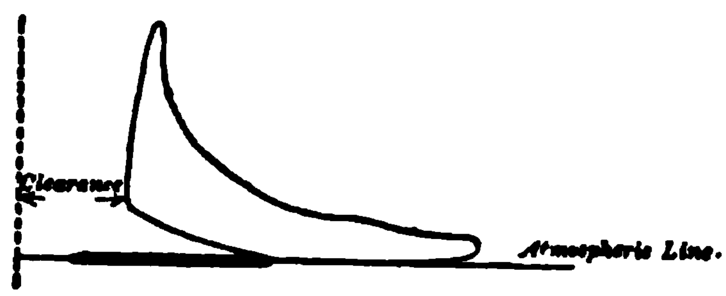


Fig. 48.—Atkinson Differential Engine—Indicator Diagram.

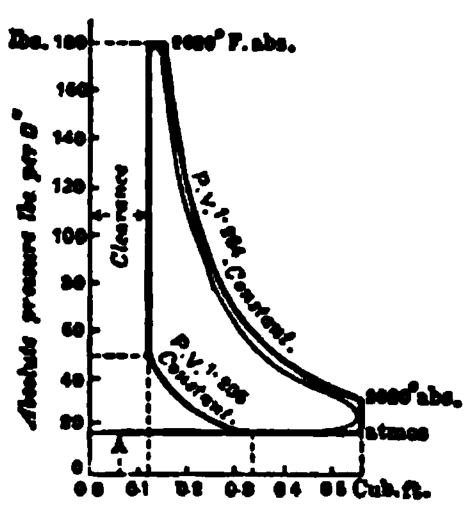


Fig. 49.—Atkinson Cycle Engine—Indicator Diagram. *Society Arts.* 1888.

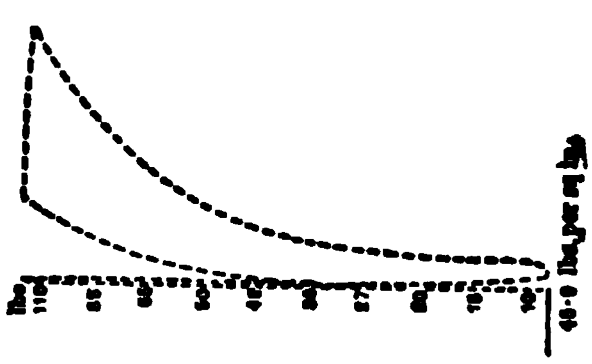


Fig. 50.—Atkinson Cycle Engine—Indicator Diagram. 1886.

consumption of gas of wholly driving out, or retaining in the cylinder a portion of the burnt products, gave an economy of 3 cubic feet of gas per B.H.P. per hour when the cylinder was thoroughly cleansed, equal to 11·7 per cent. of the total consumption of gas.

Trials.—The trials made on the Atkinson engine are given in the table at the end of the book. It has been often tested, specially by Professors Unwin, Schöttler, and Thurston. In an important experiment made by Professor Unwin in 1887, the diagram of which is given at Fig. 47, the consumption of London gas in the Atkinson engine was 22·5 cubic feet per B.H.P. per hour, and the ratio of expansion $3\frac{3}{4}$, as compared with $2\frac{1}{2}$ in the Otto. Professor Schöttler did not obtain such favourable results, but his engine was of the Differential type. Fig. 48 shows a diagram taken during the trial. The Society of Arts' experiments have been already quoted. In these the consumption of gas for the Atkinson engine was 19·22 cubic feet per I.H.P. per hour, the lowest figure recorded for any of the competing engines. A diagram of this trial is given at Fig. 49. One of the most complete tests on the Atkinson engine was made in October, 1891, at the Uxbridge Water Works by Mr. Tomlinson. In this experiment, not only the efficiency of the engine, but the value of the Dowson gas used to drive it, was determined. The engine indicated 21·95 H.P., and the consumption of anthracite was 1·06 lb. per I.H.P. per hour. Fig. 50 shows a diagram taken at this trial. The best steam engines require about 2 lbs. of good coal per I.H.P. per hour.

This ingenious engine is now no longer made, and Mr. Atkinson has recently joined the firm of Messrs. Crossley Bros., of Manchester.

CHAPTER IX.

THE GRIFFIN, BISSCHOP, AND STOCKPORT ENGINES.

CONTENTS.—Griffin Gas Engine—Varieties—Trials—Bisschop—Method of Working—Stockport—Latest Type.

The Griffin Gas Engine.—This horizontal engine, constructed by Messrs. Dick, Kerr & Co., has had considerable success in England, especially where great steadiness and regularity of speed are required for electric lighting. As formerly made, it belonged to the six-cycle type, was in a certain sense double acting, and both sides of the piston were used for expansion of the charge.

At page 62 will be found a description of the method of operations in a six-cycle engine. There are six strokes, comprising—1, Admission of charge; 2, compression; 3, explosion and expansion; 4, expelling products of combustion; 5, drawing in air or scavenger charge; 6, expulsion of charge of air. The defects of this cycle are—the want of regularity in the speed, and the loss of power due to the small number of ignitions, there being only one motor stroke in six. These disadvantages

were to a certain extent avoided in the Griffin, by making it double acting. Instead of one ignition and one working impulse every three revolutions, a charge of pure air was admitted and an ignition obtained, alternately on either side of the piston, at every one and a half revolution of the crank, and for every three strokes. Thus the action was much more regular, but the heat generated by the explosions taking place on both sides of the piston was almost as great as in the Lenoir engine. This was partly counteracted by the scavenger charge of air which, by cooling the cylinder, had a beneficial effect on the temperature of the walls. To diminish further the heat of the explosion, there was not only a water jacket to the cylinder barrel, but to the cylinder cover next the crank, through which the piston-rod worked. This had a cooling effect on the rod, and the indicator diagrams, taken during the trials of the Society of Arts, showed that the mean pressure in the front end of the cylinder was from 6 to 14 lbs. lower than at the back, where there was no cover jacket.

Some of the power generated was, of course, expended in doing negative work, or work done on the gas by the momentum of the flywheel, &c., instead of positive work of the gas on the engine. Although a six-cycle, by making it double acting, the Griffin became virtually what may be called a three-cycle engine. There were two small slide-valves driven by the counter shaft, working the admission on each side of the piston. Through them the charge of pure air was also admitted and expelled.

Fig. 51 gives a side elevation, and Fig. 52 a plan of the engine. Power is transmitted by the connecting-rod to the crank shaft K. The counter shaft R is driven from the crank shaft by worm gearing D, in the proportion of 3 to 1. It revolves, therefore, once for every three revolutions of the crank shaft. The cylinder itself, closed at both ends, stands on a base or foot B, through which the air is drawn for the motor and scavenger charges. The slide valves S S_1, driven by eccentrics from the counter shaft, contain the distributing and ignition ports; the two exhaust valves E E_1 worked by cams $c\,c_1$, and levers, are on the opposite side of the cylinder to the slide valves. In Fig. 52 the gas is admitted through two valves, d and d_1, controlled by the graduated cock n. The air enters at $a\,a_1$, Fig. 51, from the base B, and the two mingle at the admission valves $m\,m_1$. These valves are opened by cams on the counter shaft twice in one revolution, or every one and a half revolution of the crank shaft; the gas valves $d\,d_1$ open only once every revolution, or once for every three revolutions of the crank shaft. Consequently every other time the valves m m_1 open, they admit only pure air to form the scavenger charge, and every other time they admit air mixed with gas from the valves $d\,d_1$, to form the explosive charge. The gas admission valves are controlled by the governor

Fig. 51.—Griffin Six-Cycle Engine—Side Elevation.

Fig. 52.—Griffin Six-Cycle Engine—Plan. 1886.

G, by means of a cam with steps of varying width; the quantity of gas admitted is first diminished, then totally cut off, on one or both sides of the piston, according to the excess of speed.

The charge of gas and air being thus admitted at either end of the cylinder, the slide valves S S_1 worked by the eccentrics $r\ r_1$ are alternately raised once in every revolution of the counter shaft, and the fresh mixture is made to communicate through the passages shown in Fig. 51 with the permanent burners $b\ b_1$. The charge is thus fired, and the mixture explodes, driving the piston forward. The exhaust valves at E E_1, Fig. 52, are worked as in the Otto, by cams $c\ c_1$ and levers passing beneath the cylinder. These cams on the counter shaft R open the exhaust first at one end, then at the other of the cylinder, every half revolution of the counter shaft. T T_1 are the oil cups lubricating the cylinder.

Varieties.—Three types of the Griffin were made, all six-cycle engines, but the horizontal motor here described was the only one which was double acting, with one cylinder. Where it is

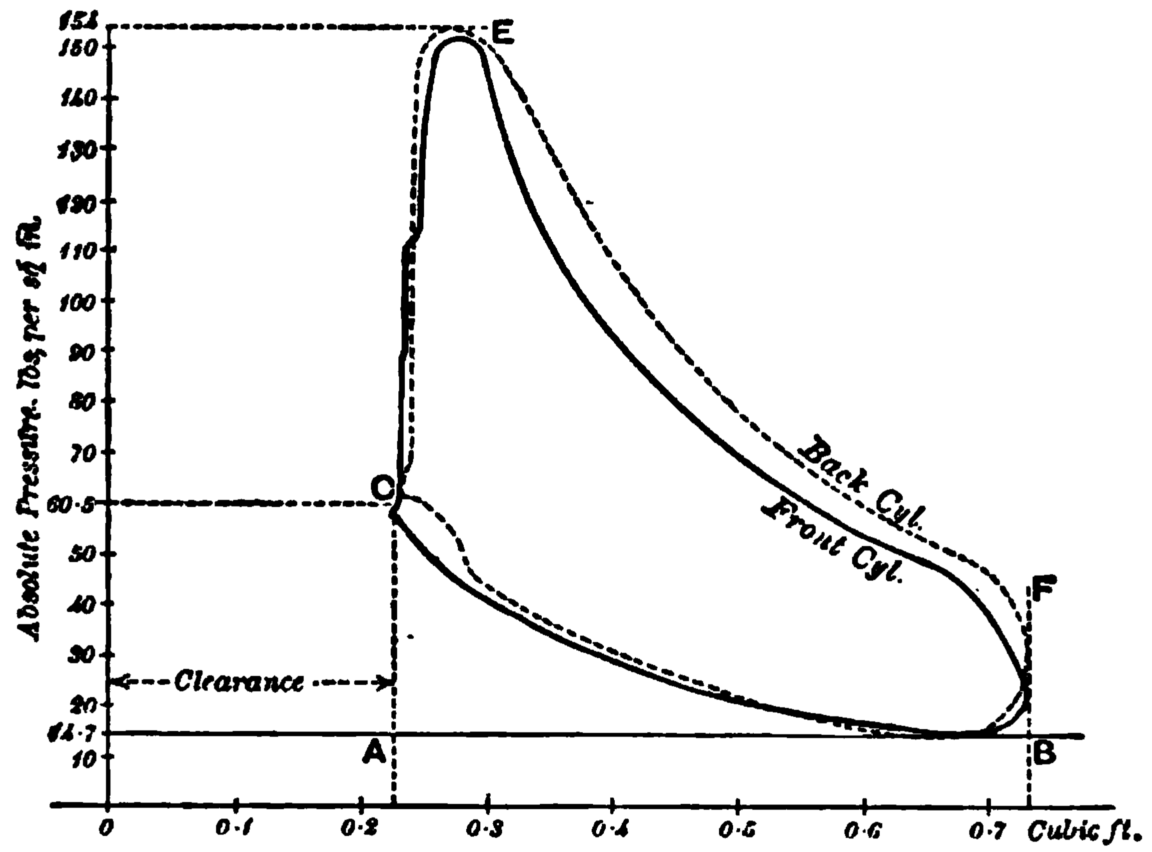


Fig. 53.—Griffin Engine—Indicator Diagram.

possible thus to utilise both sides of the piston, an engine may be constructed of half the area of cylinder, and giving the same power, at the same piston speed, as a single acting motor. Professor Kennedy found, when experimenting on a Griffin 6-cycle engine, that during a continuous run of six hours the parts were not unduly heated. In the twin-cylinder engine used for electric lighting, where great regularity in working is required, there were two horizontal cylinders side by side, each single acting, and having one motor stroke in six. In the one cylinder the cycle was three strokes in advance of the other. The forward motor stroke of one piston corresponded with the

expulsion of the scavenger charge of air in the other, and admission in one cylinder with exhaust in the other. The third type, for small powers, was made vertical, single acting, in sizes up to 6 H.P. nominal, with one explosion and one motor stroke for every three revolutions of the crank, or one working stroke in six.

Three important trials were made upon the engine, the first by Professor Jamieson, the second by Professor Kennedy, both at Kilmarnock, the third at the Society of Arts' trial competitions in 1888. In Professor Kennedy's trial an engine was tested of 14·94 B.H.P., with 23 cubic feet of gas consumed per B.H.P. hour. The indicator diagram of this trial is shown at Fig. 53. At the trials of the Society of Arts (diagram, Fig. 54), the engine indicated 15·47 H.P., and the consumption of gas was 23 cubic feet per I.H.P. and 28 cubic feet per B.H.P. hour. It should be remembered that the heating value of London, as compared with Scotch gas, is much lower. The engine was specially commended for steadiness and regularity in working.

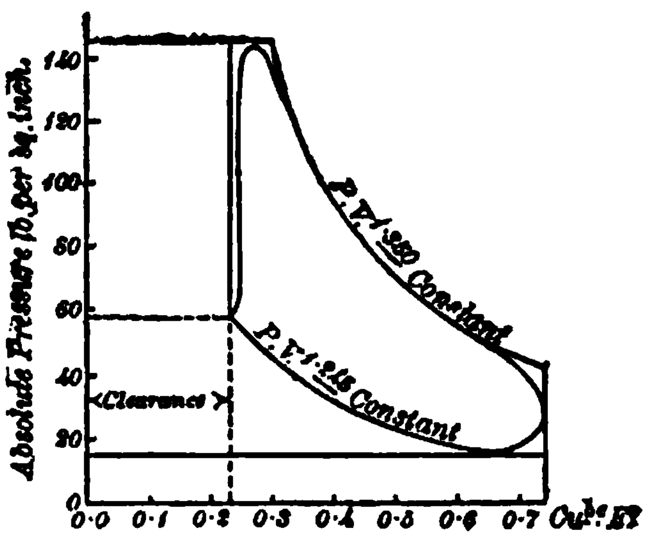


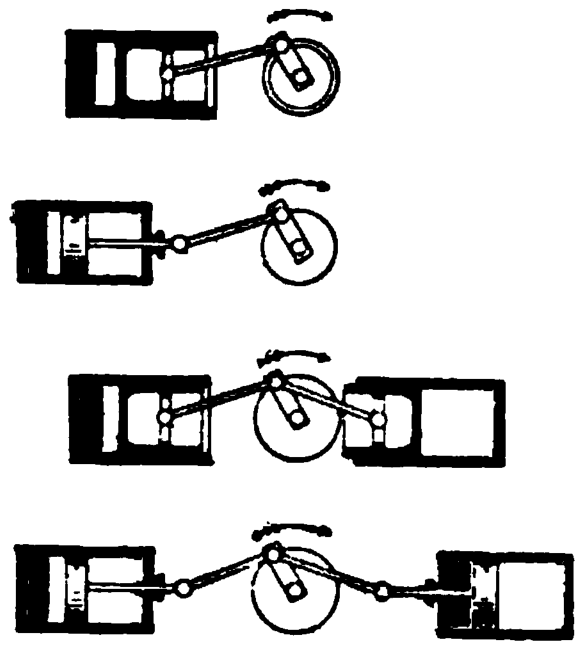
Fig. 54.—Griffin Engine—Indicator Diagram. *Society Arts.* 1888.

All the above types have now been superseded, and the Griffin engines as at present made work with the Otto cycle, the scavenger charge of air being omitted. For all powers above 12 H.P. they are constructed double acting, with explosion of the charge and motor stroke on each side of the piston. The following table shows the working method :—

Front of Piston (Crank end).		Back of Piston.
1. Forward stroke—Admission of charge. 2. Back stroke—Compression of charge.	1 rev.	1. Back stroke—Exhaust. 2. Forward stroke—Admission of charge.
3. Forward stroke—*Explosion* and expansion. 4. Back stroke—Exhaust.	1 rev.	3. Back stroke—Compression of charge. 4. Forward stroke—*Explosion* and expansion.

Lift valves are used, worked from the valve shaft, and performing a double set of functions at either end of the closed cylinder. The engines approximate to the steam engine type, having piston-rods and crossheads, the latter resting on guides. Motors intended to drive dynamos are fitted with an especially sensitive governor worked by bevel wheels from the valve shaft, which acts by controlling, but not cutting off the supply of gas,

until the load is reduced to one-third. The former arrangement of a cam with steps has been discarded in some of the larger sizes, but is retained in the smaller. In the double-acting engines the governor usually cuts out the ignitions on one side of the piston, while the cycle is carried out as before on the other. In the latest type of two-cylinder engines there is an explosion and a motor impulse at each stroke, the charge being ignited and expanded in each cylinder alternately at either end, while it is admitted, compressed, and discharged in the other. The following diagram explains the working action of the Griffin, as compared with the Otto engine:—



a b c d

(*a*) Otto — 1 explosion — 2 revs. — one cylinder, single-acting, open end.

(*b*) Griffin — 1 explosion — 1 rev. — one cylinder, double - acting, closed ends.

(*c*) Otto—1 explosion—1 rev.—two cylinders, single-acting, open ends.

(*d*) Griffin—2 explosions—1 rev.—two cylinders, double - acting, closed ends.

Fig. 55.—Diagram of Single- and Double-Cylinder Explosion Engines.

Note.—Dark mark represents explosion, 1 circle 1 rev., 2 circles 2 revs. All with four-cycle—1 stroke taking in charge, 1 stroke compressing, 1 stroke exploding, and 1 stroke exhausting.

For large powers, the Griffin engines are usually driven with Dowson or other generator gas, and an ingenious method of starting has been introduced. A large tandem engine now driving a mill at Lancaster was started with ease in a few minutes by turning the steam from the boiler of the generator into one cylinder, while the other was supplied with gas in the usual way. The pressure of the steam communicated the necessary impulse to the flywheel, until the second cylinder began to work, when the steam was turned off. This engine marks a return to the system of compound gas engines. There are three cylinders, side by side; the two outer high-pressure have a diameter of 21 inches, and 30-inch stroke; the inner low-pressure cylinder is 32 inches diameter, and 36-inch stroke. One of the high-pressure cylinders exhausts into it, the other into the atmosphere. The engine indicates over 600 H.P. with generator gas, and runs at 120 revolutions per minute.

In the electric light station at Belfast the Griffin engines are started by the dynamos, and the speed regulated by the governor acting on cams divided into layers, thus varying the time during

which the gas is admitted to the cylinders, and the strength of the explosion, but not cutting out any ignitions. This large plant consists of six engines, four with two cylinders, and two single-cylinder, all double-acting. The larger engines indicate up to 120 H.P., and generate 77 electrical H.P. Trials made on it at Belfast in 1894 by Professor Kennedy, showed a consumption of 18·2 cubic feet of lighting gas per I.H.P., and 23·9 cubic feet per electrical H.P. per hour, during a continuous run of six hours, the engines indicating 111 H.P. at a speed of 161 revolutions per minute. The diameters of the tandem cylinders were 13½ inches and 13¾ inches respectively; stroke, 20-inch. Another trial was made on a double-acting 51 B.H.P. engine by Professor Jamieson, in which the consumption of rich Kilmarnock gas was 17 cubic feet per B.H.P. per hour.

The present type of Griffin engine is made single-acting vertical or horizontal, in sizes from 1¼ to 11¼ B.H.P., and runs

Fig. 56.—Griffin (1895)—Single cylinder, double acting.

Fig. 57.—Griffin (1895)—Two cylinders, double acting.

at 190 to 275 revolutions. The double-acting engines are made horizontal, single cylinder, from 4 B.H.P. upwards, and run at 150 to 250 revolutions per minute (see Fig. 56). Above 60 H.P. they have usually two cylinders (see Fig. 57).

Bisschop.—The Bisschop engine, brought out for small powers by Bisschop in 1870-72, presents another example of a special type, and cannot be classified under any of the regular divisions of gas motors. It appeared about four years after the Otto and Langen non-compression atmospheric engine, and was intended specially to avoid the noise and recoil of the free piston, rack and clutch gear, and other defects of that motor. It belongs to what is called a mixed type. The charge of gas and air is admitted at atmospheric pressure, and the force of the explosion drives up the piston, but it is attached in a special way to the crank, and does not run free. The pressure of the atmosphere, and the energy stored up in the flywheel, then drive the piston into the vacuum formed below by the cooling of the gases. The action of the walls is here partly turned to good account, reduces the temperature of the exhaust gases, and helps to form the vacuum. In a certain sense the Bisschop, like other atmospheric engines, may be called double-acting, the force of the explosion being used on one side of the piston, and the pressure of the atmosphere on the other. With the exception of a few small French motors, it is probably the only non-compressing engine still in the market. Although originally brought out in France, it has had more success in England, and is practically a British engine.

Like all non-compressing engines, the Bisschop is not very economical, and this may be the reason why it is no longer in favour on the Continent, where the high price of gas makes economy in a gas engine of so much importance. Many cases occur, however, where simplicity and ease in starting and in handling are more necessary, and here the Bisschop, which is a most convenient little motor, has been found of use for very small powers. The English makers are Messrs. Andrew, of Stockport.

The engine has a vertical cylinder closed at both ends, and the piston-rod works in an upright hollow column. Above is a crosshead from which the connecting-rod works direct through the crank on to the motor shaft, and is parallel to the piston-rod during the up stroke. All these parts are close to the high column carrying the piston and rod, and this causes a good deal of vibration, but the impulse from the piston to the crank is direct. Explosion occurs immediately after the piston has passed over the lower dead point. The shock forces up the piston rapidly, the crank is carried round through more than half a revolution, and the connecting-rod brought parallel with the piston-rod inside the column. Thus expansion is exceedingly rapid. The distribution of the gas and air, and the discharge of the exhaust gases, are effected by a trunk piston valve, driven from an eccentric on the crank shaft. Gas and air are first admitted through valves covered with thin rubber discs; the air valve is

perforated with 18, and the gas valve with 3 holes, admitting the charge in the proportion of 6 parts of air to 1 of gas. The piston valve is then driven down, and brought into line with the distributing chamber, and the corresponding admission port of the cylinder. Cold air is also sometimes admitted into the ports at the beginning of the up stroke, to cool the products of combustion.

The engine has no water jacket, the cylinder being provided externally with ribs, to cool the metal. Strange to say, it not only works without oiling, but the manufacturers expressly stipulate that neither the piston nor the other parts shall be lubricated. A few drops of oil are applied occasionally to the crosshead and the motor crank only. Ignition is obtained by an external flame.

Fig. 58.—Bisschop Engine—Sectional Elevation. 1870.

Fig. 59.—Bisschop Engine—Section of Piston Valve.

Fig. 58 gives a sectional elevation of the Bisschop engine, and Fig. 59 a section of the piston valve. The parts are lettered alike in the two drawings; the piston valve admits, distributes, and expels the charge. A is the motor cylinder and P the piston, *c* is the connecting-rod and C the crank, K the crank shaft. G is the crosshead, and *r* the piston-rod working in it. In Fig. 58 the piston is half way through the up stroke. The eccentric *e* on the crank shaft drives the piston valve *p* (Fig. 59)

through lever *l*. The exhaust is seen at E; *k* is the small opening about half way up the cylinder, covered by a flap valve; an external flame burns behind it at *n*, and at *o* is a second auxiliary flame, to rekindle the other when blown out. Fig. 59 shows the air valve with the holes for regulating the supply, and the action of the piston valve *p*; the gas enters at *i* (Fig. 58).

Method of Working.—Beginning with the piston in its lowest position, when the exhaust has just been cut off, the pressure in the cylinder being below atmosphere, gas and air enter and mix in the distributing chamber. The eccentric drives down the auxiliary piston, and brings its opening, *m*, opposite the mixing chamber and the port *f* into the cylinder. The charge enters while the energy stored up in the flywheel carries the piston past the lower dead point. The opening *k* is next uncovered, the flap valve hanging loose before it is lifted by the vacuum, the flame is drawn in and the charge fired. Explosion follows, and the pressure closes instantly the admission and ignition valves, until the piston valve, raised by the eccentric, has shut off the distributing chamber. The piston flies up with great velocity, and more energy is generated than can be utilised in the up stroke. The reserve force carries the flywheel through the remainder of its revolution, and drives the piston down. The exhaust valve is next opened, and, during the greater part of the down stroke, the gases of combustion are driven out through the port uncovered by the piston valve, which is now in its highest position. When the pressure in the cylinder is below atmosphere, and a vacuum has been formed, the suction lifts the rubber discs covering the gas and air admission valves, the charge enters, and the cycle is repeated. The exhaust down stroke is slower than the up expansion stroke.

The Bisschop engine has no governor; the regulation of the speed is ingeniously effected by two rubber bags. The larger acts as a reservoir, and the gas passes from it into the smaller bag, which is so constructed that it receives and passes on to the cylinder exactly as much gas at a time as is required to keep the engine at any given speed. By checking the quantity of gas, the number of revolutions can be varied. The arrangement of the ignition flame is also modified in different engines, and the second flame is frequently used to heat the cylinder at starting.

Trials.—Several experiments have been carried out on the Bisschop engine, all showing a relatively large consumption of gas. Tests made at the Stockport Exhibition and elsewhere gave a mean of 139 cubic feet of gas per H.P. per hour. An experiment by Meidinger on a larger engine showed a consumption of 74 cubic feet of gas per I.H.P. per hour. This engine should not, however, be judged only by its expenditure

of gas. Neither water nor oil is required for the cylinder, and the motor was often used formerly, especially in England, to replace manual labour. Its advantages disappear when the engine is made for larger powers, although the consumption of gas is proportionately diminished.

Stockport.—The Stockport engine, made by the same firm, Messrs. J. Andrew & Co., of Stockport, was originally a four-cycle single-acting motor, in which compression took place in an auxiliary pump, and an explosion every revolution was obtained. This division of the cycle of operations between two cylinders added to the size and cost of an engine, but increased its steadiness in running. In this respect the motor resembled the Clerk, as distinguished from the Otto type, and in several working details it was similar to the original Tangye, described at p. 68.

There were formerly three types of this motor. In the first introduced in 1883, two horizontal cylinders, motor and pump, were placed opposite each other on the same axis, upon a base through which the compressed charge was conveyed from one to the other. Each had a trunk piston, the crank shaft was placed between them, and the two connecting-rods worked on to it. At first the motor carried two slide valves, a vertical valve for admitting the charge, driven from an eccentric on the crank shaft, and a horizontal slide valve, carrying the ignition flame in a hollow cavity; the latter was afterwards superseded by hot-tube ignition. There was no exhaust valve. The two pistons moved alternately in and out, the forward stroke of the pump drawing the charge through the admission slide valve, while the corresponding back stroke of the motor piston uncovered the exhaust port, and drove out the products of combustion. The following back stroke of the pump, corresponding with the forward expansion stroke of the motor, compressed the charge through the same slide valve into a hollow chamber in the base-plate. The pressure then opened a valve into the working cylinder, and the exhaust port being uncovered, the incoming charge helped to drive out the products of combustion. The return stroke of the motor piston closed the exhaust port, ignition followed, and the cycle recommenced.

With the exception of the additional pump, the parts of this engine were few and simple. As there was no exhaust valve, the exhaust ports were necessarily disposed with great care. In all gas engines the latter should have an outlet as direct as possible into the air, and not pass into drains or chimneys, and all sharp bends should be avoided. It is wise to make provision for cleaning out these ports and pipes, and many makers have now introduced some special apparatus to diminish the noise of the exhaust. The hot-tube ignition was another novel feature of this engine. At first these tubes were always made of cast

iron, and lasted only about thirty hours. Under ordinary conditions, they are rapidly burnt out by the great heat to which they are subjected, and the quick variations of temperature produce great changes and deterioration in the metal. The fresh compressed charge entering the tube at each stroke is always at a high temperature, while the residuum of exhaust gases left in it during the out stroke is relatively cooler, and through these alternations of heat the tube speedily burns away. In the Atkinson and other engines a high chimney was placed round the tube to protect it from draught, and some makers use porcelain tubes. Messrs. Andrew introduced a special composition, made of an alloy of silver, &c., which is said to last for several months, and not to fuse or cake. Ignition tubes have the advantage of being easily removed and changed when worn out, and are almost universally used in England. They are simple and regular in action, but their temperature is not so high as that of the electric spark, and ignition is perhaps more difficult. For this and other reasons the charge is often fired by electricity in France.

In the second, double-acting, type of the Stockport engine there were two motor cylinders and two pumps, all horizontal. The motor pistons worked on to the single crank placed between them. The pumps immediately below actuated a second smaller crank on the main shaft, revolving slightly in advance of the first crank. An impulse was obtained at every half revolution, and the engine ran with great steadiness. The third type was constructed for very small powers. It was vertical and had one cylinder, but the same principle of separate compression of the charge was carried out. As in the Seraine engine, a differential piston was used. The lower side, on which the charge was expanded and discharged, was smaller in diameter than the upper, on which it was admitted and compressed. Thus, the piston virtually divided the cylinder into two parts of unequal area, in which two different sets of operations took place simultaneously.

As soon as the Otto patent expired the Stockport firm, among others, adopted the Otto cycle for all classes of their engines, with various improvements in details. In their latest motors all valves are of the mushroom lift type, and are worked by levers from cams on the auxiliary shaft, geared 2 to 1 to the crank shaft. The gas valve is controlled by the ball governor, and the admission is wholly cut off if the normal speed is exceeded. In engines intended for driving dynamos, the quantity of gas admitted is reduced by means of a throttle valve before it is wholly checked; these motors also run at a higher speed. In the smaller engines a very simple governor is used, consisting of a weight on a spring, moved by a vibrating lever. For the starting gear, the advantage is claimed that, although the principle is not new, the engine itself performs the

whole operation as soon as the gas is turned on. The crank is first placed in position with the ignition tube open to the cylinder, and all other valves closed. The Bunsen burner is lit, and as soon as the ignition tube is red hot gas is admitted through a small auxiliary valve, thrown out of gear by the first explosion. The gas drives out the air in the cylinder through the ignition tube, and when it is all expelled, and the gas begins to follow it, the heat of the tube fires the gas, the flame strikes back into the cylinder, an explosion occurs, and the engine begins to work.

Modern engines for large powers are of the flat-frame type; the cylinder does not overhang, and there is less vibration and less strain upon the piston. Steam engine construction is more or less followed, and the engines have a piston-rod as well as connecting-rod, acting on the crank through a crosshead and guide.

Fig. 60.—The Stockport Engine, latest type. 1895.

The latest engines are made horizontal single cylinder, in sizes from 1 to 200 B.H.P. (see Fig. 60), and run at 240 to 150 revolutions per minute. Above this size two cylinders are used, either tandem or placed side by side. Messrs. Andrew also make portable engines from 4 to 15 B.H.P., and a small vertical type in two sizes, 1½ and 5 B.H.P., running at 220 and 200 revolutions. The larger engines can be driven with coal, producer, or Mansfield oil gas. In a 65 I.H.P. motor driving a corn mill near Tonbridge, the results of a test made with Dowson

gas gave 0·93 lb. fuel per I.H.P. hour, or 1·16 lb. per B.H.P. hour. Another test made on an engine driven by Dowson gas at Portadown, in which the indicated H.P. was 44·6, and the consumption of best Welsh anthracite 0·91 lb. per I.H.P. hour, is given in the table. A nominal 400 H.P. engine with two cylinders tandem, driven by Dowson gas, is working the Spicer paper mills at Godalming; when last seen by the author only one cylinder was working. The governor acts upon each cylinder separately, and if the normal speed is exceeded suspends the admission of gas in one cylinder only, and not in both, unless it is required by a still greater excess of speed. This firm have already made more than 7,000 motors.

CHAPTER X.

OTHER BRITISH GAS ENGINES.

CONTENTS. — Electric Lighting — Tangye — Acmé — Fielding — Forward — Small Motors — Midland — Express — Shipley — Trusty — Premier — National — Robey — Campbell — Roots — Clarke-Chapman — Dawson — Small Engines.

Two circumstances have chiefly contributed to the great development of gas engines within the last few years in England. The first is the extensive and increasing application of electricity to lighting, and the demand which has arisen for gas engines to drive dynamos in country mansions, &c., as more suitable and economical than steam. No cost is incurred with gas engines when not running. As it is seldom necessary to furnish the power for electric lights for more than a few hours at a time, a gas motor, easily started and stopped, is preferable to a steam engine and boiler, where the fire must be lighted some time before to get up steam. The economy of gas engines for electric installations is also marked, even where town gas is used. It has been found, and attention was first drawn to the fact by Sir W. Siemens, that coal gas gives much more light when furnishing power electrically through a gas engine and dynamo, than when the same quantity of gas is burnt in the ordinary way. At Dessau in Germany an electric light installation has been driven by engines worked with town gas since 1886. There are at this town one engine of 60 B.H.P., and one of 120 B.H.P., the latter is coupled direct to its dynamo. This arrangement is found to conduce, not only to increased power, there being less loss in transmission, but to economy of space, when an electric installation is required in the centre of a town. The larger gas engine showed a consumption of 39 cubic feet of town gas per kilowatt, but it is hoped with a better engine that the consumption will be reduced to 30 cubic feet of gas per kilowatt,

and 17 cubic feet per B.H.P. per hour. Where gas generators are used supplying Dowson or other power gas to the engines, the economy is much greater, the fuel costing about half that required in a steam engine and boiler, to give the same power. At Schwabing, near Munich, electricity for lighting the town is obtained from a 40 B.H.P. Otto engine, worked with Dowson gas, made from German anthracite. The consumption of fuel is 1·54 lbs. per B.H.P. hour, and 3·3 lbs. per kilowatt per hour. At Morecambe, where three Stockport engines, each of 16 H.P. nominal, are employed to drive the electric light installation, the cost when town gas was used was about 1½d. per kilowatt; with Dowson gas it is ½d. per kilowatt.* Most of the larger firms, both in England and on the Continent, now make engines for electric lighting. They run at a higher speed than ordinary motors, and the governing is more delicately adjusted, to vary the quality and quantity of gas admitted. For the Simplex gas plants see p. 146, for the Griffin installation at Belfast, p. 111.

Another reason why gas engines have become more popular in England is the expiration of the Otto patent, which has given an additional impetus to their manufacture. Hitherto the four-cycle has been found the best and simplest type of engine, working practically with as much economy as others of more elaborate construction. To avoid infringing the patent, makers had recourse to various devices to alter the working method, most of which were abandoned as soon as the Otto engine became public property. At the same time the sudden and universal competition reduced the price of gas engines, and increased their sale. Some makers had long been prepared, as soon as the patent expired, to bring out engines using the Beau de Rochas or Otto cycle.

Tangye.—Among the foremost were Messrs. Tangye, of Birmingham, who ceased to construct the engine described at p. 68 (Robson's patent), and since 1891 make engines only on the Otto principle, with Pinkney's improvements. Next to Messrs. Crossley, they at present build some of the largest motors in England. Their single-cylinder engines range from ½ to 125 B.H.P. and upwards, and two-cylinder engines from 86 to 292 B.H.P. with town gas (340 I.H.P.). The principal improvements introduced are in the combustion chamber, which is carefully constructed to prevent shock, and render the engine suitable for driving a dynamo direct, and also to ensure steady and complete combustion of the charge during the whole of the motor stroke. The pressure, as shown by the indicator diagrams, is not so high in the Tangye as in the Otto engine, but it is said to be better maintained, and expansion more complete. Messrs.

* These figures are taken from Mr. Dowson's paper on "Gas Power for Electric Lighting." *Proc. Inst. Civil Engs.*, vol. cxi., 1892-93.

Tangye also supply a pressure starter to engines above 16 H.P. nominal, which will start even large twin-cylinder motors. Gas and air are pumped into a separate receiver in such proportions

Fig. 61.—Tangye Gas Engine—Single Cylinder. 1894.

that they are not inflammable until they reach the cylinder, and mix with the air it contains. An explosive charge being thus formed at about 50 lbs. pressure, the piston is driven forward, the ignition valve hitherto held closed is uncovered, and the charge fired. Stress is laid on the fact that the engine is already in motion, and, therefore, the shock of ignition does not damage the working parts. A very sensitive governor is used, and conduces to steadiness in running. It acts by means of a cam on the side shaft upon a roller on the gas valve rod. In order to prevent a slip where the two come in contact, and hence a defective opening of the gas valve, the shaft carries a second knife-edged cam, which fits into a collar on the roller, and defines the exact point of contact between it and the governing cam.

Messrs. Tangye have, it appears, made nearly 2,000 engines since 1891, up to the end of 1895, and have especially devoted themselves to the production of large power motors. One of their latest types is a single-cylinder engine of 24 inches diameter and 30 inches stroke, driven by Dowson gas, with a consumption of 0·8 lb. Welsh anthracite per I.H.P hour (see Fig. 61). To diminish the pressure this engine has two exhaust valves, a larger and a smaller, the latter having a slight lead. The gas valve is not opened direct by the cam from the governing shaft, but the lever acts on the valve spindle through a secondary lever and tumbler; this arrangement is said to prevent wear of the heavy valves required for producer gas. The firm have lately introduced a gas generator for driving larger power motors; it is described at p. 204.

They were also the first to bring out a gas hammer for forging purposes. This useful little striker is not a gas engine driving a hammer, but the explosion of the inflammable mixture acts direct upon the hammer, and greater economy is thus obtained, since gas is used per stroke, as required. The smallest size, $\frac{3}{4}$ cwt., can deliver 120 blows per minute, or 2,500 blows at a cost of 1d. of gas, at 2s. 6d. per thousand cubic feet. The largest size has a water jacket.

The **Fawcett** engine, brought out by Fawcett, Preston & Co., Liverpool, from the designs of Mr. Beechey, is no longer made. Particulars of a trial carried out by Mr. Miller in February 1890, will be found in the Table of Trials.

Acmé.—The first Acmé engine, patented by Messrs M'Ghee, Burt & Co., of Glasgow, showed a novel attempt to solve the problem, how to increase expansion of the explosive gases in proportion to admission and compression. In this engine there were two horizontal cylinders, two pistons, and two crank shafts connected by spur wheels in the proportion of 2 to 1. The cylinders were alongside each other, one being shorter and smaller than the other. While the piston of the larger cylinder

made one stroke, the piston of the smaller made two, one crank and one shaft ran therefore at half as many revolutions as the other. The cylinder volumes and lengths of stroke also differed, and the cranks being at different angles the pistons did not work together. When the first or larger piston had completed the in or out stroke, the smaller second piston was about 45° behind. The cycle of operations was divided between the two cylinders. Hot-tube ignition without a timing valve, and discharge of the gases of combustion both took place in the smaller cylinder, the piston of which uncovered these openings near the beginning and end of its out stroke. The firing of the charge and the exhaust were timed to occur when the first piston was at positions corresponding to the inner and outer dead points. An engine of this type was shown at the Crystal Palace Electrical Exhibition (1892), and another at Erfurt, in 1894, by the Maschinen bau Werkstätte, Mulhouse, Alsace, formerly Ducommun, and also at Antwerp.

Several sizes of this engine were tested, both with full load and running light, by Professor W. T. Rowden, of Glasgow. In 1888 and 1889 he experimented upon engines of 2 H.P. nominal, running at 170 revolutions per minute. A trial at full power gave 3·14 B.H.P., and a corresponding consumption of 18·1 cubic feet of gas per hour. Professor Rowden made experiments in 1890 on a larger engine of 6 H.P. nominal, in which the B.H.P. was 8·28, and gas consumption 17·3 cubic feet per B.H.P. hour. In a further trial of the same engine the B.H.P. was 7·8, and the gas consumption as low as 16·83 cubic feet per B.H.P. hour. Allowance must be made for the richer quality of Glasgow as compared with London gas; their heating value is about as 9 to 10 per cubic foot.

A new four-cycle type of this engine has lately been brought out to supersede the former. Except in the tandem engines there is only one cylinder, in which the usual functions of admission, compression, explosion and expansion, and exhaust are carried out. The chief novelty lies in the method of valve gearing. Gas and air are admitted to a mixing chamber at the back of the cylinder through mushroom valves. A double-headed piston valve, worked by a small crank from a side shaft geared by wheels of equal diameter to the motor shaft, runs behind and at right angles to the cylinder, and through ports between the two pistons of this valve the charge of gas and air enters. The outward movement of the valve piston next closes the admission openings, and uncovers the ignition tube. The charge is fired, and the gases of combustion are driven out by the return stroke of the motor piston through ports uncovered by the further motion of the valve piston. In one respect the principle of the former engine is adhered to. The admission ports are shut off when the motor piston is three-quarters through its admission

stroke, but compression and expansion both occupy one whole stroke, and thus are greater in proportion to the quantity of gas and air admitted than is usual in four-cycle motors. In their 6 H.P. engine, the makers claim a consumption of 18½ cubic feet of Glasgow gas per B.H.P. hour. The inertia governor acts on the hit-and-miss principle upon the gas valve, and regulates the consumption. The engine is made in sizes from 2½ to 100 B.H.P., horizontal, single cylinder, and runs at 160 to 200 revolutions. A vertical type having two cylinders, sometimes tandem, sometimes side by side, intended specially for driving dynamos, is made in sizes from 60 B.H.P. upwards, and runs at about 400 revolutions per minute.

Fielding.—This engine, made by Messrs. Fielding & Platt, of Gloucester, is constructed on the principle of the Otto, and has the same cycle; the slide valve is abolished, and the parts are simple. There is hot-tube ignition, but no timing valve to the smaller engines, though for larger sizes it has been found necessary. A timing valve is constructed to open the part leading to the hot ignition tube, at the exact moment when an explosion is required. Punctual ignition is a necessary feature of all gas engine cycles. Some inventors, however, have succeeded in dispensing with the timing valve, and they maintain that, by varying the length of the ignition tube, and the distance from the red-hot metal to the motor cylinder, accurate ignition can be obtained. The gases do not reach this heated part of the tube until the end of the in stroke, when compression is greatest. Ignition at the dead point has been one of the main features of the gas engine theory since the time of Beau de Rochas, and it may be doubted whether it is really so easily obtained as these inventors assert. The practice of dispensing with the timing valve is sanctioned by no less an authority than Mr. Atkinson.

In the Fielding & Platt engine, the organs of distribution and exhaust and the oiling apparatus are driven, as in the Otto, from a side shaft worked by worm gear from the main shaft. The valves are opened by cams. Another cam actuates the governor, which is simply a small dash pot, with a piston connected to a lever opening the gas valve. If the speed be too great, the dash pot cannot overtake the motion of the engine, and is left behind; it drags back the piston, raises the lever, and the gas valve remains closed. Several large sizes of this engine were exhibited at the Royal Agricultural Society's show at Doncaster in 1891, when it was brought to public notice for the first time. The makers claim a gas consumption of 17 to 25 cubic feet per I.H.P. per hour, according to the size of the engine, and quality of gas used. It is now made horizontal from 1·9 to 80 B.H.P., and vertical 1¼ to 2½ B.H.P., and runs at 200 to 160 revolutions per minute.

A well designed horizontal type, indicating 100 H.P., has

also lately been brought out. There is one "mitred-seated" valve for admitting the charge and expelling the burnt products. A piston valve driven by an eccentric on the crank shaft opens communication between the inlet and exhaust cylinder ports and this valve, the rod of which is worked by a cam. Ignition

Fig. 62.—Fielding & Platt Gas Engine—Single Cylinder. 1894.

is by hot tube, and there is a timing valve in this engine, acted on by the same eccentric as the piston valve. All these organs are contained in a valve chest at the side of the motor cylinder. This engine is also provided with a special starting gear, consisting of a reservoir, into which air is compressed by the action of the piston. To start the engine the cylinder is first filled with

gas, and the supply cocks being closed, the compressed air is then allowed to enter. This method is said to be powerful enough to start an engine with partial load on. The engine has a ball governor which controls both the air and admission valves. The quality of the charge is varied in proportion to the speed, but there are no "cut-outs" or miss fires. It is illustrated in *Engineering*, January 27, 1893; Fig. 62 gives an external view.

Forward.—The Forward engine, made by Messrs. Barker & Co., of Birmingham, is really a simplified Otto. The Beau de Rochas cycle is used, but several improvements have been introduced. There is no admission slide valve, and ignition is by a hot tube, as in most modern English gas engines. The chief novelty is the device used to obtain punctual ignition of the charge without a timing valve. The opening of the tube is covered by a rotating disc, with "hit-and-miss" slots; the surface of the disc is divided into radiating sections, alternately pierced and solid, which, as the disc revolves, are brought successively across the ignition port. According to the section of the disc facing it, the ignition port communicates with, or is shut off from, the cylinder. This arrangement is found in several foreign engines, and is not altogether new. In some of the Forward engines a ball governor, in others a rotary governor, is used, and arranged to regulate the speed of the engine in three different ways. It controls the admission of the charge of gas and air into the combustion chamber and, at the same time, the rotatory motion of the disc. Unless there is a charge in the chamber, the disc cannot open the ignition port, nor can the charge pass into the chamber, unless an open slot faces the ignition port. Lastly, the governor acts upon the supply of gas, and cuts it off altogether, should the speed increase greatly beyond the normal limits. The same cylinder port serves for admission and exhaust. By this arrangement the port is said to be kept cool, and the waste of mixed gases prevented. For starting the Lanchester apparatus is used. The engine is made in sizes from 2¾ to 53 B.H.P., and runs at 200 to 160 revolutions per minute, or rather faster, if used to drive a dynamo. Only horizontal single cylinder engines are constructed, and if more power be required the engines are coupled.

Careful tests have been made on the Forward engine by Prof. Robert Smith, of Mason College, Birmingham, and by Mr. Holroyd-Smith, and both these experts have reported favourably. During trials of several hours the engine ran very steadily, and was found to work well, even under the severe test of counting the revolutions every ten seconds, instead of every minute, and varying the weight on the brake as rapidly as possible. The real test of regular working in an engine is absence of fluctuations in the speed, when the load is suddenly

put on or taken off, as in electric installations. In a test made by Professor R. Smith with full working load the speed was 176·86 revolutions per minute, and the explosions 59, or 1 for every three revolutions. In another at half load the number of revolutions was 177, with 57·8 explosions per minute, or 3·06 revolutions per explosion. The consumption per I.H.P. per hour was in the first trial 20·79 cubic feet of Birmingham gas, and 23·97 cubic feet per B.H.P. hour. The mechanical efficiency was 86 per cent. Another trial was made at the Birmingham Gas Works in 1894 on a 22·85 B.H.P. engine, in which the gas consumption was 21 cubic feet per B.H.P., and 17¾ cubic feet per I.H.P. hour. The mechanical efficiency was 84 per cent. For these trials see table.

Small Motors.—Of the numerous gas motors lately brought out in England and abroad, many are made almost exclusively for small powers. These little engines do not vary much in type; their main recommendation is not so much economy of gas, as lightness, simplicity, and the ease with which they are started and worked. In many industrial operations the use of small gas motors often makes the difference between a profit or a loss to the employer, particularly with the difficulties of modern labour.

Midland.—The first engine of this name, manufactured by Messrs. John Taylor of Nottingham, had two cylinders, motor and pump, both single acting, and fixed upon the same frame. The engine was made both vertical and horizontal. In the vertical type the two cylinders were side by side, and each piston worked upon the motor shaft, by means of a separate crank. The charge was admitted and compressed in the pump, and exploded, expanded, and discharged in the cylinder, thus giving an explosion every revolution. There were no slide valves, cams, or wheels; the admission valves were driven by an eccentric and rod on the main shaft, and the gas valve connected to a centrifugal governor. Ignition was by a hot tube, the upper portion of which was kept at a red heat by a Bunsen burner. No timing valve was used, the length of the tube determining the moment of ignition. The gases were driven into the lower end of the tube by the down stroke of the compressing piston, and ignited only when the maximum pressure was reached, and they were forced into the upper part.

Messrs. Taylor have now given up the manufacture of this type, and, like many other firms, make engines exclusively on the four-cycle principle, single cylinder and chiefly horizontal. The admission of the charge is effected by rods and levers from a small crank, worked from the main shaft by worm gearing; the exhaust is driven by an eccentric from the same shaft. A ball governor controls the gas supply. The engine is made horizontal in sizes from 1¼ to 23 B.H.P., and sizes over 6 H.P.

are fitted with a self-starting apparatus. The speed is 220 to 180 revolutions per minute. A small vertical type named the "Dot" is made from 1 to 4 H.P. nominal, and runs at 200 to 340 revolutions.

Express.—The Express, made by Messrs. Furnival & Co., of Reddish, near Stockport, is another single cylinder gas engine which has appeared since the expiration of the Otto patent. In design, construction, and cycle of operations it closely resembles that engine. Admission is by ordinary lift valves, with hot-tube ignition. The side shaft is driven in the usual way by worm gear from the main shaft, and a centrifugal governor acts on the gas valve. The engine is made in sizes from 2 to 50 H.P., and runs at 200 to 160 revolutions per minute.

Robson's Shipley.—Mr. John Robson, of Shipley, makes a small single-cylinder type, in sizes from ½ to 6 H.P. constructed on the same principles, and using the same cycle as the Otto, with lift valves and hot-tube ignition. The engines are horizontal for larger, vertical for smaller powers. The gas, admission, and exhaust valves are worked by cams on the side shaft, geared to the main shaft in the usual proportion; there is a ball governor, and no timing valve.

Trusty.—This engine, made by Messrs. Weyman & Hitchcock, of Guildford and Cheltenham, is a well-constructed motor using the four-cycle, and having an explosion every two revolutions. The valves are worked by a side shaft driven from the main shaft. Hot-tube ignition is used without a timing valve, the tube being inverted. This novel arrangement is intended to procure more certain ignition, because that part of the tube nearest the cylinder is hotter than when the tube is upright. In the latest engines the governor consists simply of a weight attached to one arm of a lever swinging on a pivot, the other shorter arm of which opens the gas valve, unless the normal speed be exceeded. An 8 B.H.P. engine was tested at the Crystal Palace Exhibition in 1892, when the consumption of gas was found to be 24 cubic feet per B.H.P., and 15·45 cubic feet per I.H.P. per hour. This engine is made horizontal, single cylinder, in sizes from 2½ to 46 I.H.P., and runs at 200 to 160 revolutions per minute. A little vertical type with two cylinders running at 180 to 300 revolutions has lately been introduced, intended for marine and electric work. It develops 11 H.P., and occupies a very small space; and is also made in all sizes, with two or three cylinders side by side for driving dynamos. For a description of the engine as used with the Connelly tramcar see p. 388.

Premier.—The Premier engine, made by Messrs. Wells Bros., of Sandiacre, near Nottingham, works with the four-cycle and hot-tube ignition, and without a timing valve, except in the larger sizes. The side valve shaft is geared 2 to 1 to the main shaft. In the smaller engines an inertia governor is used, consisting of

a bar with a weight at one end and a notched jaw at the other, working on to a lever opening the gas valve. Above the bar is

Fig. 63.—Premier Gas Engine, 1894. Two cylinders, single acting.

a disc rotating at the same speed as the engine. Each time the disc completes a circuit, a pin upon it is brought round to the jaw, pushes down the bar, and opens the gas valve. But if the

disc rotates at too great a speed, the pin upon it slips past the jaw, and no gas is admitted. In the larger engines, especially those at high speed for electric lighting, the governor acts by throttling the supply of gas before it wholly cuts it off. Thus the quality of the charge is first affected, and ignitions are only missed if the normal speed is greatly exceeded. The engine is started by a pump which injects gas and air, while a catch holds the ignition valve closed. As soon as the mixture is sufficiently compressed, the catch is released, an explosion follows, and the engine begins to work. The Premier is made single cylinder, horizontal, in sizes from ¾ to 85 I.H.P.; vertical, 2 and 4½ I.H.P., and runs at 150 to 300 revolutions per minute, according to size. Both types are also made to run at higher speeds for electric lighting. Two sizes, 60 and 120 B.H.P., are also made with two cylinders, either tandem (see Fig. 63) or side by side, and run at 140 to 180 revolutions. All sizes above 30 B.H.P. are fitted with an arrangement for introducing a scavenger charge of pure air, to cleanse the cylinder of the burnt products. This is effected, without departing from the four-cycle, by means of a second larger piston placed in front of the motor piston, which acts as a pump, and draws in and expels a charge of fresh air. The two-cylinder engines have an impulse every revolution, and the governor acts by suppressing the ignitions first in one, and then, if necessary, in both cylinders. Each engine has its own governor worked by wheel gear direct from the crank shaft. The largest tandem sizes have hitherto been made only for use with Dowson gas.

National.—The National horizontal single-cylinder engine, made at Ashton-under-Lyne, is another four-cycle motor, with hot-tube ignition and lift valves worked from a side shaft. It is in sizes up to 75 I.H.P., and the makers say they have sold over 1,000 in four years.

Robey.—This horizontal engine is made by Messrs. Robey & Co., of Lincoln (Richardson and Norris patents), for driving dynamos, for electric lighting, and other purposes. It has heavy fly wheels, and the ball governor, as usual with this class of motor, is extremely sensitive; it acts on the gas valve by means of a lever and small roller. The usual four-cycle is employed. Ignition is by a tube heated by a Bunsen burner; a double-headed valve with two seats is used to fire the charge, and great accuracy of ignition is obtained. There are no timing valves to these engines, but by a special arrangement the moment of ignition can be adjusted to suit the speed. The number of revolutions can also be readily altered, and the engine made to run, if required, at a low speed during the day, and at a high speed at night. A patent "safety combination" is provided to prevent starting backwards, and by altering the eccentric lever the motion of the engine can be reversed. Coming from so well

known a firm this motor, well designed and constructed, has already proved a success. It is started by means of the Lanchester self-starter. A small type, the "Novelty," has lately been introduced, made in sizes from ½ to 2 B.H.P., and running at 550 to 250 revolutions. It has no valve levers, but the three valves for air, gas, and exhaust are worked direct by cams on the auxiliary shaft. The Robey engine is made in all sizes from ½ to 240 B.H.P., and runs at 230 to 140 revolutions, according to size. For powers above 72 B.H.P. two cylinders are generally used. Drawings are given in *The Engineer*, October 14, 1892.

Two small single-cylinder engines, the Bradford, made by Clayton at Bradford, and the Purnell, by the makers of that name at Atlas Works, Blackfriars, both work with the four-cycle. The Purnell has only two valves, for admission and exhaust, driven from a side shaft, and no timing valve. It is made vertical, in sizes from ¼ to 8 B.H.P., and runs at 250 to 200 revolutions. The Bradford is both vertical and horizontal, in sizes from 1¾ to 26 I.H.P. The Gardner, another small engine, is made at Colne in Lancashire, from ¾ to 4½ B.H.P.

Campbell.—The engine of this name, manufactured by the Campbell Gas Engine Co., Halifax, England, is another four-cycle motor, with hot-tube ignition and a ball governor. It is made both vertical and horizontal, in sizes from 2¼ to 85 I.H.P., and runs at 160 to 300 revolutions per minute.

Roots.—The special feature of this engine, invented by Mr. Roots, is that the pressure of the exhaust gases is utilised to give a second working stroke. In other words, the engine is partly double-acting, having a motor impulse on either side of the piston, but combustion takes place on one side only. The usual operations of admission, compression, explosion with expansion, and exhaust are gone through on one side of the piston. The exhaust gases, instead of being discharged, then pass through ports uncovered by the piston to a space on the other side containing compressed air, and the gases at a high temperature and pressure and, according to the maker of the engine, still in a state of flame, raise the air to a pressure of about 30 lbs. per square inch, and act on the piston to drive it back. Thus the complete cycle is again gone through, with the exception of explosion, the charge already admitted and compressed being expanded and discharged as before. This double utilisation of the heat of combustion ought to effect a considerable economy. The engine is made in sizes from ½ to 15 B.H.P., and runs at 370 to 200 revolutions per minute. Ignition is by a hot tube, and the speed is regulated by an oscillating weight governor.

Clarke, Chapman & Co. (Butler's patent).—An engine has lately been brought out by this firm which, although not entirely new, since several foreign makers have utilised the idea with

slight variations, does not seem to have been previously introduced into England. The usual ignition, admission, and exhaust valves have been replaced by a single circular, rotatory valve, worked by an auxiliary shaft geared to the crank shaft by worm wheels 4 to 1, thus rotating once every four revolutions or eight strokes. This slow motion is intended to prevent wear and tear, the various functions being carried out alternately on opposite sides of the piston valve. The revolving valve has two ports for the supply of gas and air, and two for exhaust, corresponding with the two passages to the cylinder, shown on the drawing in the oil engine section, p. 338, Fig. 128. The arrangement there is similar to that of the gas engine, with the addition of a vaporiser. If hot-tube ignition is used, the circular

Fig. 64.—Clarke-Chapman Gas Engine—Single Cylinder. 1894.

valve also carries two ports for opening communication between the tube and the cylinder at the proper moment.

The gas and air are first admitted, the air through a nozzle, and the gas through a small screw regulating valve to an annular space round it, and thence to a mixing chamber beyond. This device is called the inspirator. The charge then passes to a throttle valve controlled by the governor, as in a steam engine. It is admitted through the ports in the circular valve to the cylinder, and compressed, ignited, expanded, and discharged in the usual way. The makers prefer to ignite the charge electrically, and supply a coil and battery; a timing commutator is then fixed on the valve shaft. This method of ignition is said to facilitate starting, but if tube ignition be required, the hot tube is fixed immediately over the valve casing. There is no timing

valve, explosion at the right moment being effected through the circular valve. The engine is regulated by a weight governor on the flywheel. If the normal speed is exceeded the weights fly out, and act through a shaft upon the throttle valve in the admission pipe, diminishing the quantity entering the cylinder more or less according to the excess of speed. The quality of the charge is never varied, and as the governor does not interfere with the working of the circular valve, there is an explosion at every cycle, whatever the load. The pressure of admission is regulated by the governor according to the work, the speed being kept practically the same. The engine is started by a small hand pump, which forces a properly proportioned mixture of gas and air into a chamber, from whence it passes through a

Fig. 65.—Dawson Gas Engine—Single Cylinder. 1894.

valve into the cylinder, and is ignited either by the burner or, preferably, by electricity. The engine is made horizontal in sizes from 2 to 100 B.H.P.; no tests appear to have been yet published. An external view is shown at Fig. 64.

Dawson.—The novelty of this engine, which is made by the Dawson Gas Engine Syndicate, is the high speed attained. It is constructed single cylinder, vertical, in sizes from ½ to 20 B.H.P., and runs at from 1,600 to 600 revolutions per minute, but no trials have yet been made upon this interesting little motor. For powers from 50 H.P. upwards, two cylinders side by side are used. The advantages claimed for these very high-speed engines are, that there is less internal friction, owing to the smaller cylinder surface and smaller dimensions required,

and that a small quantity of gas, if exploded exactly at the right moment (a point of much importance), and rapidly expanded, will do more work than a larger quantity more slowly expanded.

The engine is vertical, as shown in Fig. 65, the cylinder above, the crank below, and both are enclosed. It is lubricated from a small recess below the piston, from whence the oil is splashed over the working parts. Ignition is by a tube inside a furnace, and is brought to an intense heat by means of a small air blast. Perfect ignition even of a weak charge is said to be thus obtained, with the great rapidity required in these high-speed engines, 1,000 ignitions per minute being sometimes procured. The engine has only one valve for gas, and no levers or cams. The functions of ignition, exhaust, and admitting the charge to the cylinder are effected by the rotatory motion of the piston around its own axis, in addition to its reciprocating motion to and fro. This novel arrangement is carried out by two worm wheels, one on the crank, and one on the crank shaft, causing the hollow piston, which has ports in its sides, to uncover successively corresponding openings in the cylinder walls. Thus the admission, firing, and exhaust of the burnt products are all obtained by the motion of the piston. The speed is regulated by a pendulum governor. The engine can also be adapted for oil or generator gas, but hitherto it has only been used with lighting gas, and requires it is said about 20 cubic feet per B.H.P. hour.

The **Gorton** engine is made on the Otto cycle from 1½ to 28 B.H.P. The makers claim to be able to vary the speed from 100 to 400 revolutions per minute, while the engine is running. A high normal rate of speed is attained, 300 revolutions, and the charge is said to be very rapidly exploded and expanded.

The **Dudbridge**, by Messrs. Humpidge & Holborow, Stroud, and the engine constructed by the Gas and Oil Engine and Dynamo Co., Queen Victoria Street, London, are new single cylinder motors of the Otto type. They are made both vertical and horizontal, in sizes from 2 to 56 B.H.P., and run at 160 to 250 revolutions. For driving dynamos the speed is increased. The Dudbridge has a ball governor and hot-tube ignition.

Messrs. Grice and Sons, Birmingham, have brought out the "**Birmingham**" gas engine (Grice & Rollason's patents), a four-cycle, single cylinder, horizontal motor, specially intended for driving freezing machinery on the ammonia compression system. The engine is very simple, with few parts; lift valves are used, with hot-tube ignition and a pendulum governor. It is made in sizes from 2¼ to 55 B.H.P., and runs at 150 to 250 revolutions per minute.

A small gas engine with the Otto cycle is made by Messrs. Norris & Henty, in sizes from 1½ to 8 I.H.P.; the smallest sizes run at 250 revolutions. It has no side shaft; the exhaust is worked by an eccentric on the crank shaft, the other valves are automatic.

CHAPTER XI.

FRENCH GAS ENGINES—THE SIMPLEX.

CONTENTS.—Cycle—Electric Ignition—Slide Valve—Governor—Starting—Cheap Gas—Trials.

AMONG the various engines which have appeared during the last few years, to compete with the Otto, few have been as good in design, and as economical in working as the Simplex. It was brought out by MM. Delamare-Deboutteville and Malandin in 1884, and constructed by MM. Matter & Cie. at Rouen. The Otto firm contended that their patent had been infringed in France, and brought a law suit against the proprietors of the Simplex. In 1888 it was decided by the judges in favour of the latter. Although the Beau de Rochas cycle is used in their engine, and the method of operations resembles that of the Otto, several essential differences have been introduced, and the ignition, regulation, and self starter are new. One important modification has been made in the cycle. Ignition takes place when the piston has moved a little, and not, as in the Otto and most other gas engines, at the dead centre, or before the piston has moved. The engine is horizontal, of the single cylinder, single-acting type.

Simplex Cycle.—In other respects the usual sequence is adhered to. There are four operations, each occupying one stroke—viz., 1st forward stroke, admission; 1st return stroke, compression; 2nd forward stroke, explosion and expansion; 2nd return stroke, discharge of the gases. Hence there is one

explosion for every two strokes forward and two strokes return, or every two revolutions, and one motor impulse in four. The compression space is more restricted, and the gases are more highly compressed previous to explosion, than in the Otto engine. Formerly, when ignition was effected by a flame carried in a movable slide valve, high initial pressures of the gases were difficult to manage, as the flame was frequently extinguished. For this and other reasons the electric spark is preferred to ignite the charge in this engine, and renders the pressure of the gases, as far as the force and certainty of the explosion are concerned, a matter of indifference. Whether they are highly or slightly compressed, ignition is equally prompt and effectual. High initial pressures and temperatures are a source of economy, because a poorer mixture can be used, and less gas is required. The piston, being allowed to move out a little way before the explosion takes place, works more easily and quietly. There is less shock to the bearings, and not only the pressure of the gases, but the pureness of the mixture is increased, and the products of combustion more completely expelled, because of the smaller space into which the charge is driven.

Electric Ignition.—After careful study of all the different methods of firing the charge in gas engines, MM. Delamare-Deboutteville and Malandin decided in favour of electricity. Their system obviates nearly all the drawbacks attaching to this method of ignition, except that a battery and coil are required to generate the sparks. The working expense of igniting by electricity is said to be about one-fourth less than the hot tube. Of all the many devices hitherto resorted to for firing the explosive mixture, none of them can be called perfect. The plan originally adopted by Otto, but since almost wholly discontinued, of carrying a lighted flame to and fro in the slide valve, was open to many objections. The great heat to which the slide valve was subjected, due not only to the continual explosions, but also to the permanent gas flame burning outside, soon deteriorated the quality of the iron, made the joints shrink, and coated the ports with carbon. Ignition by a hot tube has not these disadvantages.

In France firing by electricity has been generally adopted. As employed by Lenoir and his successors, the system was defective, and there were frequent miss fires. The positive wire from a Ruhmkorff coil was conducted to the two opposite ends of the cylinder, the negative to the engine itself, and the circuit closed or interrupted by a contact maker. Premature ignition often occurred, and when the electric spark was generated inside the cylinder itself, the points of the wires became coated, and sometimes no sparks were produced. The inventors of the Simplex have adopted the ingenious method of introducing the two ends of the wires into an isolated chamber

in the slide cover, and allowing a continuous stream of sparks to play between them. A slide valve moves to and fro between the slide cover and the cylinder, at half the speed of the crank shaft. At a given moment, a zig-zag passage in the slide valve is brought opposite the ignition chamber, and opens communication between it and the admission port into the cylinder. Part of the charge, already highly compressed by the back stroke of the piston, rushes through the passage, is fired by electric sparks, and ignites the mixture in the cylinder. The moment of ignition, therefore, is regulated, not by the generation of the electric sparks, but by the movement of the slide and the edges of the port. Premature ignition is prevented by isolating the wires in porcelain tubes.

To work well, this method of ignition requires a pure explosive mixture, and that no gases of combustion from the previous charge should be left in the firing chamber or the slide valve. At the moment when the compressed gases, driving before them any residuum of burnt products, pass from the cylinder into the oblique passage in the slide valve, and $\frac{1}{150}$ part of a second before the edges of the passage are brought opposite the firing chamber, a small hole opens communication with the outer air. This little vent-hole is obliquely in line with the firing chamber, to which it is connected by a grooved channel in the slide valve and face. So great is the pressure of the incoming charge, that all the burnt gases are discharged through this opening in even less than the time allotted, and the fresh purified charge is ready to be exploded. This system of ignition has been found economical and convenient. The slide valve and firing chamber are kept comparatively cool, and require less attention than with flame or hot tube ignition. The regulation of the speed is another special feature of the Simplex engine. Two ingenious methods are employed, according to the size of the engine; and the governors are novel in application, if not in principle.

Fig. 66 gives a side elevation, Fig. 67, a back view, and Fig. 68 a sectional plan of the Simplex engine. In outward appearance it somewhat resembles the Otto, having a single horizontal cylinder open at one end, working direct through a connecting-rod on to the crank, and a counter shaft to act upon the organs of admission, distribution, ignition, and exhaust, driven by worm gearing from the crank shaft. A is the motor cylinder, P the piston, C the connecting-rod, and K the crank shaft. E, Fig. 68, is the wheel on the crank shaft, and F another wheel gearing into it, of double the diameter, driving the side shaft R, which makes one revolution for every two of the crank shaft. B is the base plate, M the mixing chamber for the gas and air at the back of the cylinder. So far the construction is the same as in many other engines; the horizontal slide valve S, Fig. 68, is

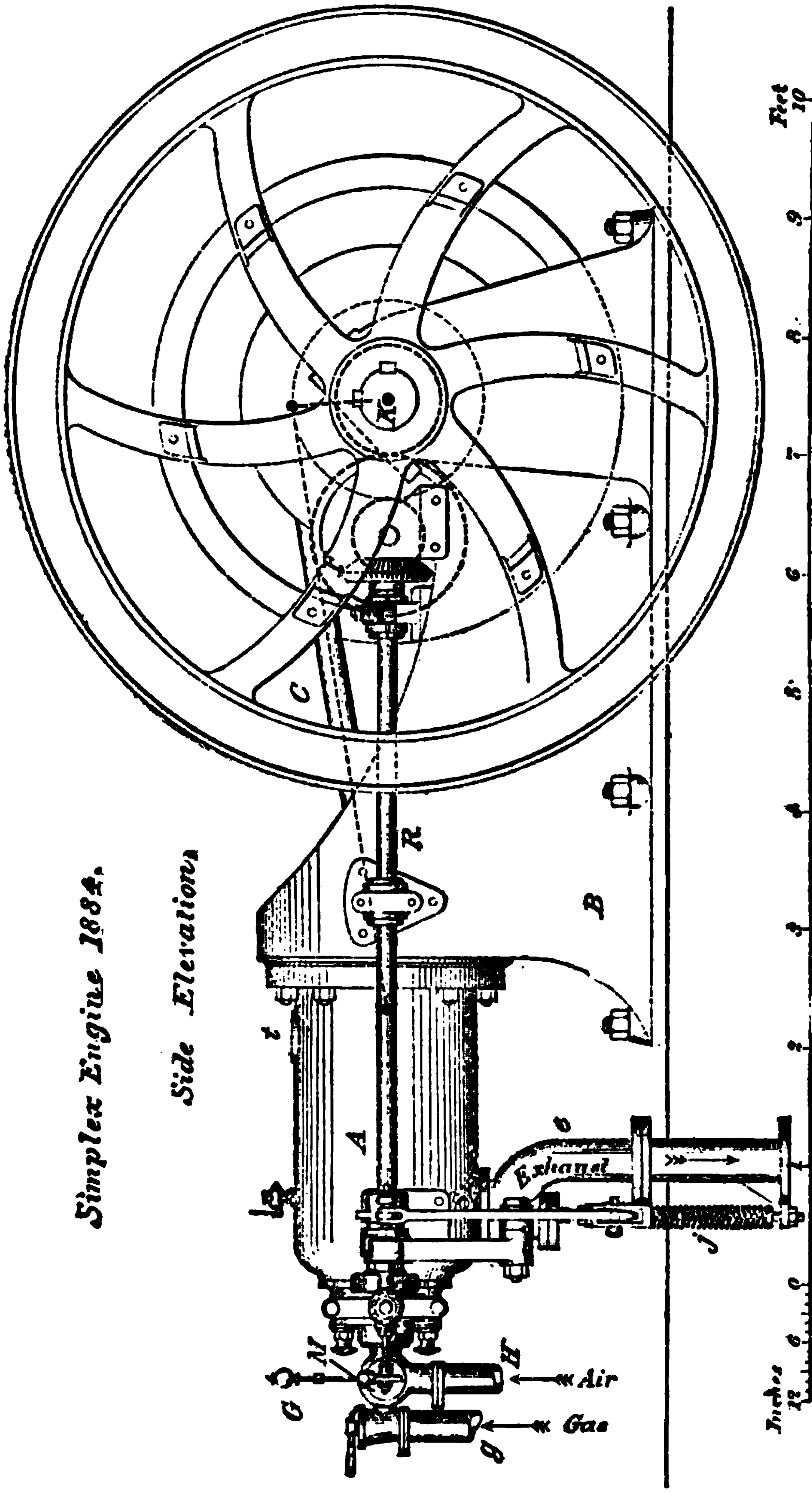


Fig. 66.—Simplex Engine—Side Elevation.

also driven to and fro by the side shaft R in the usual way. In Fig. 67, V and V_1 are the flywheels, and U and U_1 the pulleys.

The cylinder is cooled by a water jacket, the water enters at *t*, and is discharged at t_1, Fig 68. *e* is the exhaust opening at the bottom of the cylinder communicating with it through the valve S_1. The air enters at H, the gas at *g*, through a pipe at right angles to it, seen in Fig. 67. Both pass into the distributing chamber M, and from thence through slide valve S into the small chamber B_1 in the rear of the cylinder, where they are compressed by the back stroke of the piston. It is the relatively small size of this compression space in proportion to that of the cylinder which causes the gas and air to be more highly compressed than in most gas engines. In an engine of 6·7 B.H.P.

Fig. 67.—Simplex Engine—End View.

tested with town gas by Professor Witz, the volume of the compression space was 32·4 per cent. of the total cylinder volume. With gas of poorer quality, such as Dowson, the volume of the compression chamber is only 25·6 per cent.

The side shaft terminates in a small crank, *k*, working the slide valve, and moving it once to and fro for every two revolutions of the crank shaft. The discharge pipe for the exhaust gases is seen at Fig. 66. The exhaust pipe *e* is closed by the valve S_1, held upon its seat by the spring *j*. At a given moment

Fig. 68.—Simplex Engine—Sectional Plan. 1884.

a cam upon the side shaft R presses down one end of the lever L, the other end rises, releases the valve S_1 from the spring *j*,

and pushes it up, and the exhaust gases pass out through *e*. As the pressure in the cylinder is 1½ atmosphere when the exhaust opens, the valve is lifted a little before the end of the stroke, to avoid back pressure on the piston.

Slide Valve.—Fig. 69 shows a sectional plan of the organs of admission, distribution, ignition, and the air governor, all of which are at the back of the cylinder. S is the slide valve, *k* the small crank on the counter shaft working it, and M the distribution chamber. This chamber has three openings, the first for the admission of air from below at H, the second, *g*, for the entrance of the gas, the valve of which is controlled by the air governor G to the right; the third leads through the slide valve into the cylinder, the arrows indicate the direction. At I is the ignition chamber, into which the ends of two electric wires surrounded by porcelain insulators are introduced, and a continuous stream of sparks plays between them, without heating the metal. The slide valve has only two openings, a rectangular passage, *e*, shown at Fig. 69, in line with the cylinder port and distribution chamber, and an oblique opening, *f*, which, as the slide moves to the right, brings the lighting chamber I into communication with the cylinder through the same port. The admission passage is first circular in form, then conical, lastly rectangular, and it is thus shaped to ensure the thorough mixing of the gas and air as they pass to the cylinder.

Simplex Governor.—Two simple and ingenious methods of regulating the speed have been adopted in this engine. For small motors, MM. Delamare and Malandin use an extremely sensitive air-barrel governor. If the speed be too great, the governor wholly cuts off the supply of gas, and this method is not only economical, but by admitting air only for one or more revolutions, the cylinder is thoroughly cleansed of the burnt products, and the next explosion is stronger, because the mixture is undiluted. The governor also regulates the supply when the engine is running light. The slide valve S, Fig. 69, carries a small horizontal cylinder, *c*, cast with it in one piece, and therefore making one movement forward and back for every revolution of the crank *k*, or every two revolutions of the crank shaft. The piston and rod of this cylinder are stationary and fixed to the slide cover, and the cylinder, contrary to the usual arrangement, slides to and fro over them with the movement of the slide valve. Rubber rings allow the piston-rod to move in a slightly oblique direction, as the cover is tightened against the slide valve. At the opposite end of the cylinder *c* is a small opening, *k'*, through which air is admitted and driven out by the piston at each forward movement of the slide; the quantity of air is regulated by a micrometer screw, and only so much enters at each stroke as will fill the cylinder. At right angles to, and cast in one piece with, the upper cylinder *c* and

Fig. 69.—Simplex Engine—Section Plan of Admission Valves, Air Governor, &c. 1884.

the slide valve is a second smaller cylinder, *n*, the piston of which is free, and usually rests against *c*. The piston-rod ends

in a knife edge, *o*, fitting into the rod opening the gas valve. If the speed be normal, a cylinder-full of air is taken into and expelled from cylinder *c* at each to and fro movement of the slide valve. The piston of cylinder *n* does not move, and the knife edge *o* being brought each time by the motion of the slide against the gas valve-rod, pushes the valve open, and admits a certain quantity of gas. But if the speed be too great, the slide valve and, consequently, the cylinder *c*, make more than the given number of movements. More air is admitted into cylinder *c* than can be driven out during one revolution. It is compressed, the pressure acting upon the piston in *n* drives it down, and the knife *o* misses the edge of the gas valve-rod,

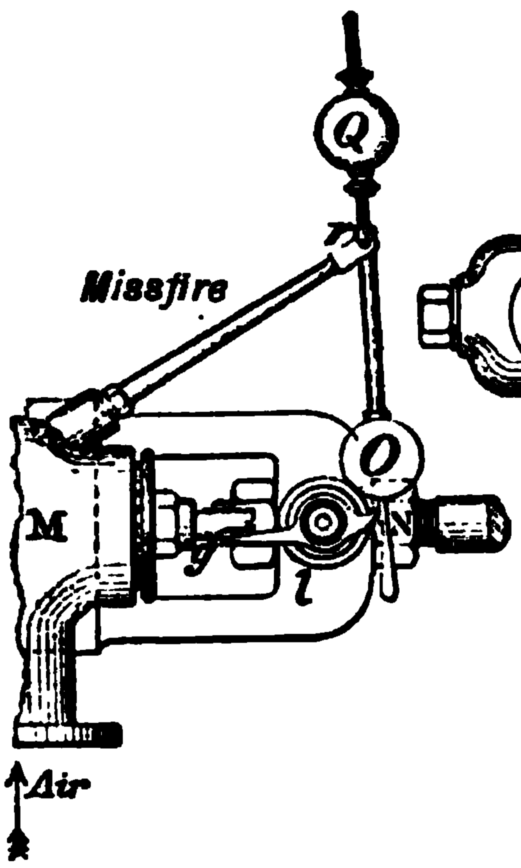


Fig. 70.—Simplex Engine—Pendulum Governor.

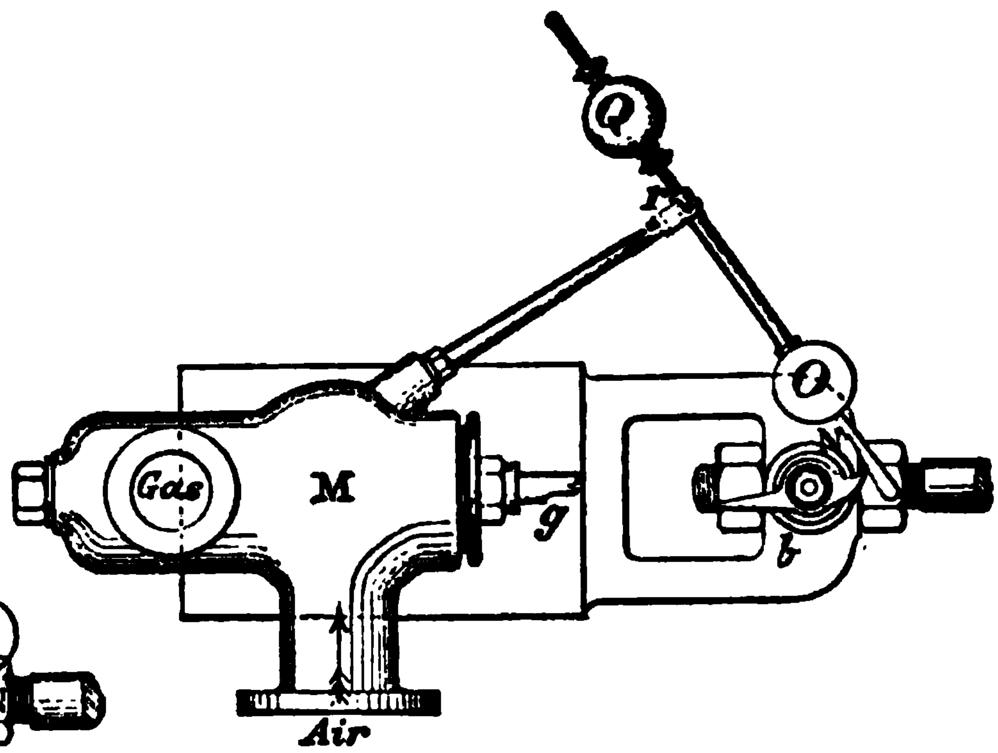


Fig. 71.—Simplex Engine—Pendulum Governor. 1888.

as seen in the dotted line, Fig. 69. No gas can thus enter until the speed of the engine and, consequently, the pressure in the upper cylinder, are reduced.

For larger engines a simpler and cheaper governor has been introduced. It is constructed on the principle of two pendulum weights, a lighter and a heavier, swinging on a fixed pivot at either end of a rod. The time occupied by the fall of the pendulum is always the same; the variation in the speed is obtained by a weighted knife blade acting upon the gas valve. Figs. 70 and 71 show the arrangement of the pendulum governor, also seen in Fig. 67. The two weights of the pendulum, Q and O, are mounted on a rod ending in a notch, N, and held in position by the pivot *r* in the centre. The heavier weight O is fixed to the lower end of the rod; the upper and lighter weight can be adjusted by a screw to any distance from the middle of the rod,

to give the required length of swing for any speed. The heavier weight being below, the tendency of the pendulum is always towards an upright position. Bolted to the slide valve of the engine, and therefore moving to and fro with it, is a frame carrying a knife blade, *b*, square and weighted at one end, and pointed at the other. The pendulum and the notched opening of the gas valve *g*, shown to the left, are both in the stationary valve cover, the weighted blade on the frame moves with the slide valve. As the square part of the blade is the heavier, the piece of iron, unless prevented, always remains vertical; but each time the knife blade in its motion encounters the pendulum as it swings, the point of the blade is caught by the notch and held in position, and the square end of the knife pushes open the gas valve. If, however, the speed of the engine be too great, the slide valve carries the knife blade forward too soon, as seen in Fig. 70. The blade misses the notch, the weighted end drops below the gas valve, and no gas is admitted. This governor is almost as sensitive as the other, because, the fall of the pendulum being always the same, the regulation of the speed depends on the hit or miss of the notch.

From this description it will be seen that the Simplex engine differs in many important respects from the Otto, especially in the ignition, which, M. Delamare asserts, is simpler, cleaner, and more certain than the usual firing. The higher pressure obtained by reducing the compression space, the greater heat of the electric spark, and the more complete discharge of the exhaust gases, increase the economy and efficiency of the engine, and make it especially fitted for driving with Dowson or other poor gas. To set up a complete gas-generating plant, however, is only remunerative for large power engines, and it is under these circumstances that the Simplex reaches its maximum of economical working.

Starting.—The construction of the engine renders it easier to start than most other gas motors. As the electric spark is sufficiently powerful to ignite gases at any pressure, preliminary compression, always a difficult matter, is not necessary to any large extent. A simple method of starting was introduced and patented by MM. Delamare and Malandin in 1888. A three-way cock, shown in plan, section, and elevation at Fig. 72, is connected to the ignition and main gas supply. The gas is admitted from below, and the air at the side into the ignition chamber, and pass through the oblique slide valve opening into the cylinder in the direction of the arrows. Fig. 73 shows a diagram of the movements of the piston.

The special and original feature of the Simplex self-starter is that the explosive mixture, instead of being introduced during the admission stroke, enters the cylinder during the third or expansion stroke. All attempts to start the engine when

admitting the charge as usual during the first forward stroke failed, because so long a time elapsed—viz., a forward (admission) and back (compression) stroke, before it was fired. But as soon as the "lucky idea," as the inventor calls it, was hit upon, of admitting the charge at the beginning of expansion, the engine was easily started, because the gases were immediately fired, and driven out during the course of the next exhaust stroke.

To set the engine in motion, therefore, the piston must be stopped at *c*, Fig. 73, at the end of compression, and the compressed gases allowed to escape. The gas cock and the three-way cock are then opened, and the flywheel turned by hand, until the piston has moved to *e* through three-quarters of its next forward stroke. Gas and air, mixed in the proportions allowed by the openings of the three-way cock, enter the cylinder to fill the vacuum caused by the forward motion of the piston. The cocks of both pipes are then turned off, the movement of the flywheel reversed, and the piston returning to e_1, slightly compresses the

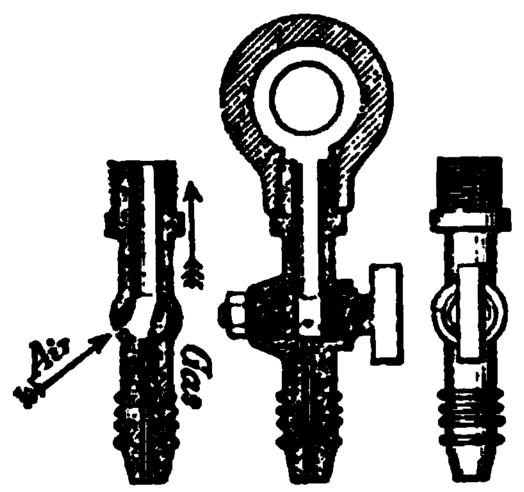


Fig. 72.—Simplex Engine—Starting Gear.

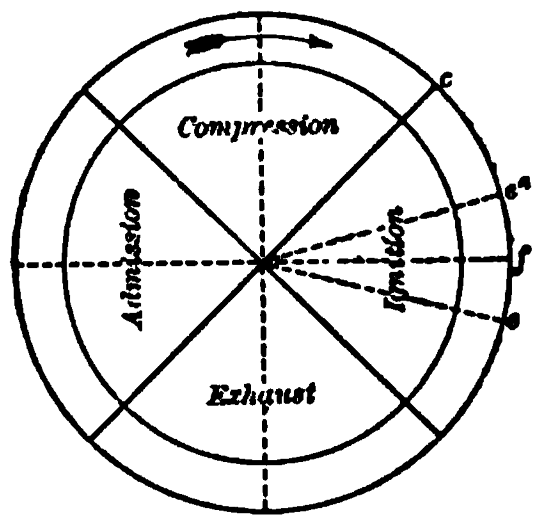


Fig. 73.—Simplex Engine—Positions at Starting.

charge of gas and air behind it. The electric current is then switched on, and although the gases are at a low pressure, the spark is sufficiently powerful to ignite them, an explosion follows, and the engine is fairly started. For larger engines, where it is difficult to turn the flywheel by hand, the engine is started still more easily and simply. It must be stopped at *f*, Fig. 73, in the middle of the ignition stroke, and the gas and air allowed to enter through the three-way cock. At the top of the cylinder, above the compression chamber, there is a small hole closed by a pet-cock. This is opened, and the mixture of gas and air entering the cylinder at a slight pressure drive out, through it, the burnt products remaining from the previous charge. As soon as the hole is closed, the three-way cock being still open, the gas and air accumulate behind the piston and in the ignition chamber. The ordinary gas cock is then opened, a fresh charge enters, the current is switched on, an explosion follows, and the engine begins to move. In the later engines the pet-cock is

replaced by an auxiliary cam on the counter shaft, which keeps the exhaust open and diminishes the pressure, until the engine is at work. In both these methods of starting the principle is the same, namely, to introduce gas into the cylinder by other than the regular means, and at an unusual period in the cycle.

The single cylinder 100 H.P. nominal Simplex engine attracted much attention at the Paris Exhibition of 1889, and was highly commended for economy and efficiency. Worked with Dowson gas made in a special generator, the consumption of coal per I.H.P. per hour was about half that in a steam engine of the same power. This engine was one of the best representative types then made of an economical gas motor. It had two flywheels, the diameter of the cylinder was 23 inches, length of stroke 3 feet 2 inches. The mean speed was 100 revolutions per minute, and the initial pressure of the gases 6 atmospheres. The saving effected by the use of Dowson gas, instead of the expensive Paris gas, was very marked. For further particulars see Table of Trials. The Simplex engines, all single cylinder, are made in sizes from 1 to about 150 H.P., for use with town gas; for Dowson or other poor gas from 30 to 400 H.P.

MM. Delamare and Malandin have now adopted the Lencauchez system of power gas, described at p. 206, for driving their larger engines, and have erected several important plants, combining the Lencauchez generator and the Simplex engine. Forty-seven have been put up in France during the last few years. The most important, and one of the largest motors now at work, is at the Pantin Flour Mills near Paris. The gas is supplied by two Lencauchez generators. The engine is single acting, with one cylinder 2 feet 10 inches diameter, and 3·28 feet stroke, and runs at 100 revolutions per minute. The quality of the charge, the ignition, and action of the exhaust and admission valves can all be varied at will. The engine was tested while driving the mill for 194 consecutive hours, during which the indicated H.P. was about 280, and brake power 220 H.P., mechanical efficiency 78 per cent. The consumption of non-bituminous Anzin coal (French) was 0·80 lb. per I.H.P., and 1·0 lb. per B.H.P. hour. The heating value of the gas was 152 B.T.U. per cubic foot (mean). For large gas engines M. Delamare is of opinion that further progress should consist in improving gas generators, and adapting them to work with any kind of coal, to reduce the cost of the fuel used per ton.

Another important gas engine plant is at Linet's Chemical Works at Aubervilliers, near Paris. Three Simplex 80 H.P. gas engines work a set of dynamos, which transmit the power electrically, with very little loss, to the different machines. The engines and dynamos act on shafts placed underground to economise space, the gas is supplied by two Lencauchez gener-

ators, and both engines and generators can be disconnected and worked separately. In a test made in 1894 the consumption was 1·4 lbs. coal per B.H.P., and 1·1 lbs. per I.H.P. hour. At Étrepagny, in Eure (France), the town and private houses are lit by electricity, generated by a horizontal single cylinder Simplex engine driven by Lencauchez gas. In a trial by M. Bourdon the engine developed 62·55 B.H.P., and the consumption in the generator was 1·3 lbs. per B.H.P. hour of French coal. The station supplies 330 private, and 60 street lamps at a cost of about 14s. 6d. a year for an 8-candle power lamp, or double that price for a 16-candle lamp. The water supplied to the town of Laval is also raised by pumps driven by an 80 H.P. Simplex engine worked with generator gas. The whole plant, including the pumps, requires the attendance of only one man. The normal speed of the pumps is 30 revolutions, raising about 900 gallons of water per minute. The consumption is said to be about 1¾ lbs. coal per hour per H.P. of water lifted. At the Lyons Exhibition in 1894 the tramcars were driven for some months by electricity generated from a 120 H.P. Simplex engine.

A curious application of this motor is at a small factory for distilling tar, acetic acid, and other products from wood, at Lisors, Eure. The water under pressure required for the work is pumped by an 8 H.P. Simplex engine, driven by the uncondensed gases given off during the process of distillation. These gases, which would otherwise be lost and wasted, are thus utilized, and power is obtained at a nominal cost. This application of gas engines may become of importance in countries where wood is abundant.

Trials.—Most of the tests described will be found in the table. Professor Witz's experiments on the 100 H.P. engine at the Paris Exhibition were continued for four successive

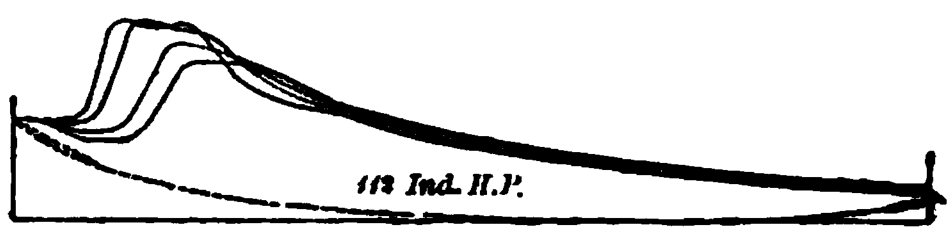


Fig. 74.—Simplex Engine—Indicator Diagram.

days, and the calorific value of the Dowson gas used was 170 B.T.U. per cubic foot, at ordinary temperature and atmospheric pressure. The B.H.P. of the engine was 75·86, and the consumption 1·3 lbs. coal per B.H.P. hour. Fig. 74 shows a diagram taken during the trial. In a smaller engine tested by Professor Witz in 1885 the B.H.P. was 6·8, and the consumption of lighting gas 21·8 cubic feet per B.H.P. hour. An engine of nearly twice the size showed a brake consumption of 19·4 cubic feet per hour. Fig. 75 is an indicator diagram from an 8 H.P. engine.

The Simplex engines are now used in France for various important mills, flour, cotton, weaving, silk, electrical works, &c., and compete seriously with steam engines at about half the cost of fuel per H.P. All these motors are made on the four-cycle

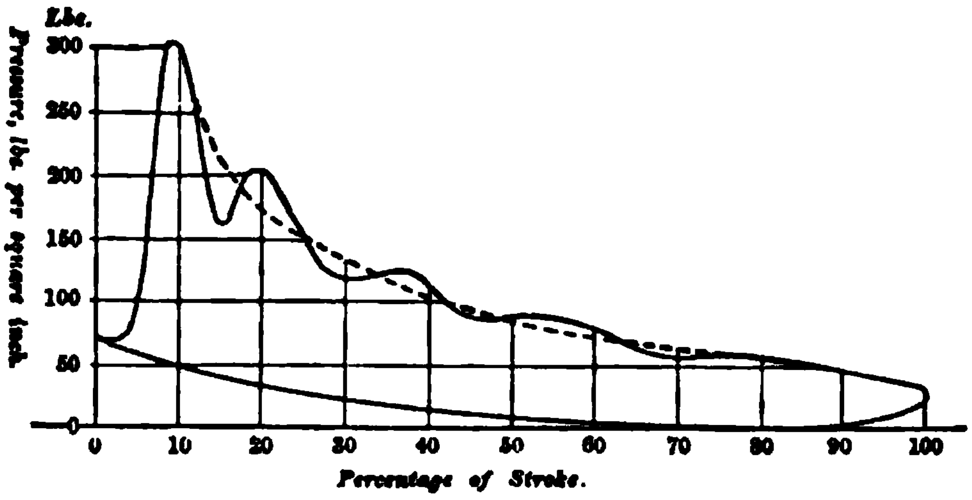


Fig. 75.—Simplex Engine—Indicator Diagram of 8 H.P. Engine.

principle, horizontal, single cylinder, and single acting. The speed varies from 200 revolutions in the smallest engines to 100 revolutions per minute in the 200 H.P. engines.

CHAPTER XII.

THE SECOND LENOIR AND OTHER FRENCH ENGINES.

CONTENTS—Second Lenoir—Charon—Tenting—Forest—Niel—Durand—Perrin—Crouan—Roger—Le Robuste—Brouhot—Letombe—Bénier.

SINCE the introduction of his first motor in 1860, Lenoir, the pioneer of gas engines, had been incessantly working to perfect his invention and to remedy its defects, especially the large consumption of gas. Sixteen years later, in 1876, a new direction was given to the efforts of mechanical engineers by the appearance of the Otto. The success of this motor conclusively proved the truth of Beau de Rochas' theory that, without compression of the gases before ignition, it is impossible to make an engine work economically. Abandoning, therefore, the lines on which he had formerly worked, Lenoir announced his adherence to the principle of compression by introducing, in 1883, an engine in which the Beau de Rochas cycle was closely followed.

Second Lenoir.—Like the Otto, the second Lenoir engine has one motor impulse in four. The first stroke (forward) draws

in the mixture of gas and air, the second stroke (return) compresses the charge; during the third stroke (forward) it is exploded and expanded, doing positive work; and in the fourth stroke (return) the products of combustion are discharged. The cycle of this new engine is generally similar to that of the Otto, and like the inventors of the Simplex, Lenoir had to encounter a lawsuit in France, which was decided in his favour in August, 1885. There are, however, essential points of difference, as well as of resemblance, in the two motors. Lenoir aims at obtaining higher compression of the gases. By separating the chamber in which they are compressed from the working cylinder, and keeping it hot, while the cylinder is cooled by a water jacket, he contrives to heat the gases before ignition, without unduly raising the temperature of the piston. As in the former engine, the electric spark produced for each explosion is employed to ignite the gases, but his particular method of ignition does not seem to give a perfectly regular speed. Whatever its merits when skilfully handled, it is, in the opinion of Professor Schöttler, a step in the wrong direction to fire the gases electrically. In other respects the mechanical details of this Lenoir engine are good, and carefully studied. The high pressure at which the gases are ignited gives greater expansion after explosion, the mixture can be much diluted or a poorer gas used, and greater economy is thus obtained. The piston moves out so little during explosion, that ignition practically takes place at constant volume.

The cylinder is in reality divided into two distinct parts, the motor cylinder, in which the piston works, and the compression chamber at the back, separated from it by an asbestos joint. This chamber, called by the inventor a "reheater," is a distinguishing feature of the engine. The cylinder is surrounded by a water jacket, but radiating cast-iron ribs, offering a considerable surface to the air, are sufficient to cool the compression chamber, because the piston does not enter it. Thus the incoming gases, as they pass through this chamber, which is much hotter than the cylinder, are heated prior to ignition, and the heat imparted to them increases their pressure. Before explosion it rises to 4 atmospheres (about 60 lbs.), and after explosion to 13 atmospheres, and to 16 atmospheres in engines using carburetted air. This high pressure and temperature make the gases ignite easily, although a poor and greatly diluted mixture is used. Another novelty in this engine is that the admission and ignition valves are at the side of the cylinder, in a relatively cool position, and therefore need little oiling. The electric wires never come in contact with the lubricant, and there is no danger of the ends becoming greasy. Air and gas are admitted and mixed in a distributing chamber, as seen in the drawing.

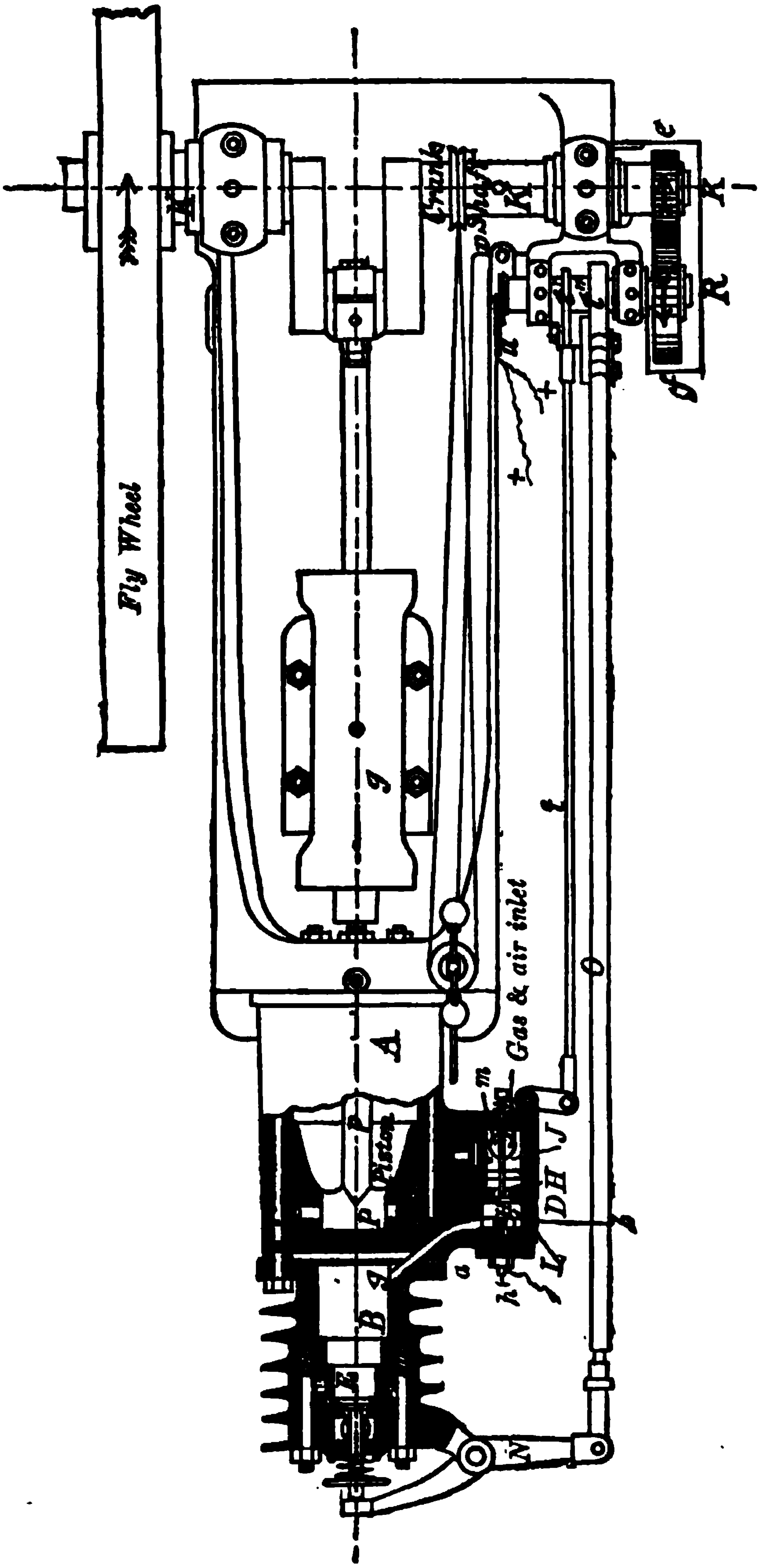


Fig. 76.—Second Lenoir Gas Engine—Sectional Plan. 1863.

Fig. 76 gives a sectional plan of the second Lenoir engine, showing the different parts. A is the motor cylinder, with piston P, B the compression chamber surrounded by the external ribs, E is the opening for the exhaust at the further end of the compression chamber, D the valve chest at the side of the cylinder, containing chambers for the admission, mixing, and ignition of the charge. At *a* is the asbestos joint separating the cylinder casting from that of the compression chamber, to prevent the conduction of heat. A portion of the piston-rod is seen at *p*, working through the connecting-rod and a strong cylindrical guide *g* on to the crank shaft K. All the organs of admission, distribution, ignition, and exhaust are worked by a counter shaft, R, driven from the main shaft by two spur wheels, *e* and *f*, in the proportion of 2 to 1. The shaft R, therefore, revolves at half the speed of the crank shaft. Upon it are two cams, *t′* and *t″*, and a projection, *v*; these work the exhaust and admission valves, and the ignition. The exhaust E is opened by the lever N and the rod O. At a given moment the cam *t″* on the counter shaft pushes out the valve-rod O, the lever N is displaced, and the exhaust port uncovered.

The valve chest D is divided into two parts, J the admission, and I the mixing and ignition chambers, and communication between them is made through a horizontal valve, H. The air enters from below at *m*, and the gas from above; the governor acts upon the gas admission pipe. To admit the gas into chamber J, the second cam *t′* on the counter shaft R pushes out the rod *t* and lifts a valve placed on the gas supply pipe. Unless checked by the governor, the gas enters through several holes, and becomes thoroughly mixed with the air, before the valve H opens to admit the charge into the inner chamber I. From thence it passes through the channel *g* into the cylinder, and is compressed into B. The charge is fired at *h* on the same principle as in the earlier Lenoir motors. Two wires, positive and negative, pass from a Ruhmkorff induction coil, the one into the engine, the whole of which becomes negative, the other from *u* to *h* at the side of the admission chamber. Contact is interrupted or established by the projection *v* on the counter shaft R, which at a given moment in the cycle of the engine closes the circuit. The spark is produced, and part of the highly compressed charge in B, driven up the narrow passage *g* by the return compressing stroke, is ignited, and spreading back into the cylinder fires the remainder. The passage is always open to the cylinder, but the charge cannot ignite until the maximum pressure is reached, and the spark produced. An indiarubber bag is used to regulate the pressure of the gas. Little difficulty is apparently found in starting this engine, the process being always easier in engines firing electrically than in those which use flame ignition. The counter shaft R carries

a second smaller cam, as well as the cam opening the exhaust, and both can be brought into play when starting. By means of the second cam, the exhaust valve is opened twice during one revolution of the crank, to diminish the pressure of the gases in the cylinder. As soon as the engine is at work, the handle moving this cam falls back automatically. The gas valve can also be opened independently of the governor.

M. Tresca, who had been the first to experiment upon the original Lenoir motor, undertook two series of trials upon the modern engine, driven alternately with gas and with carburetted air. Tests were made on a 2 H.P. nominal engine with Paris gas in 1885, and the mean of three experiments gave a consumption of 24 cubic feet of gas per I.H.P. per hour. The indicator diagram is shown at Fig. 77. The engine ran at 176 revolutions per minute, and the mechanical efficiency was 74 per cent. The dimensions of the cylinder are given in the table. Another experiment was made in 1890 by M. Hirsch on a 16 nominal H.P. Lenoir engine, in which the consumption of Paris gas per B.H.P. per hour was a little over 21 cubic feet. It must not be forgotten that in all engines firing the charge electrically, the consumption of gas is slightly less than where flame ignition is used, because in the latter case a small quantity of gas is required to feed the light. M. Tresca died before the results of his experiments were published. The constructors of the Lenoir engine claim for it an average consumption of 23 cubic feet of Paris gas per I.H.P. per hour.

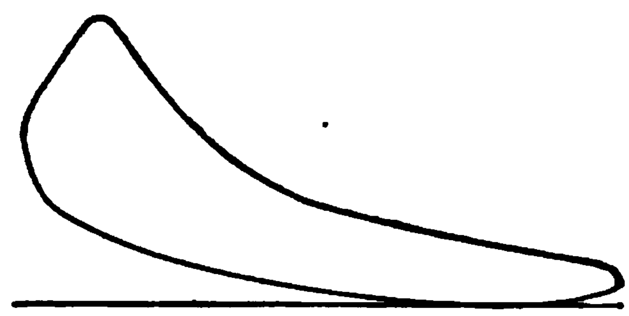


Fig. 77.—Second Lenoir Engine—Indicator Diagram.

For sizes above 8 H.P., the Lenoir motor is usually made with two cylinders and pistons, working upon the same crank shaft. A single counter shaft between them drives the admission and ignition valves and the governor. There is only one mixing chamber, communicating alternately with each cylinder, and one commutator, to pass the spark to either cylinder as required. One explosion per revolution of the motor crank is thus obtained. Sometimes all the parts are made in duplicate, and the engine virtually consists of two single cylinder motors. The modern Lenoir engines are made at Paris by M.M. Rouart Frères, and by the Compagnie Parisienne d'Éclairage au Gaz, horizontal in sizes from $1\frac{1}{3}$ to 8 H.P., single cylinder, and run at 220 to 160 revolutions per minute; and with two cylinders up to 50 H.P. with a speed of 160 to 140 revolutions.

Charon.—This engine was patented in 1888, and shown in the French section of the Paris Exhibition in 1889. It is a horizontal four-cycle motor, resembling the Otto in outward

appearance and mechanical details, with lift valves and electric ignition. To obtain greater expansion in proportion to admission and compression of the charge, a novel feature has been introduced in the construction of this engine. The student will already be familiar with various devices of this kind, but the method employed by M. Charon, although complicated, is original and ingenious, and has been praised by such well-known authorities as Witz and Chauveau.

As in most types of engine using the Beau de Rochas cycle, the piston makes two forward and two return strokes for every revolution. The charge is fired by an electric spark a little before, or exactly at the end of the compression stroke. There are two valves, one to admit gas alone, the other for the admission of the charge of gas and air to the cylinder. In the latter valve the air enters centrally from below, and the gas circumferentially through a number of small holes immediately below the valve seat. The chief novelty of the engine is that, when

Fig. 78.—Charon Gas Engine. 1895.

the piston has reached the end of the first out stroke, with the full charge of gas and air behind it, the gas valve closes, but the admission valve remains open during the first part of the return stroke. This valve communicates through a pipe with a spiral coil in a cylindrical chamber shown to the left in the drawing, Fig. 78. At the top of the latter the air enters, and is drawn through the spiral coil before it passes to the admission valve. As this valve does not close at once, a portion of the gases, instead of being compressed in the cylinder, passes into the spiral passage, driving out the air in the latter. The valve then closes, and during the remainder of the stroke the charge is compressed

by the piston in the usual way, ignited, expanded, and discharged. When the cycle recommences the admission valve again opens as well as the gas valve, and part of the gases stored up from the previous charge are first drawn in, then air from the atmosphere through the chamber. The next compression stroke refills the spiral coil.

The usual operations are effected by lift valves worked by cams on a side shaft. There are four cams, actuating respectively the gas valve, the valve admitting the charge to the cylinder, the ignition and exhaust. The electric wires are carried into a small chamber at the back of the cylinder, immediately above the admission valve. Contact is interrupted by a lever moved by a cam on the side shaft, and the spark is produced just before the crank reaches the inner dead point. Great care is taken in this engine to determine the precise moment of ignition. The speed is ingeniously regulated in the following way:—The ball governor acts not only on the gas cam, but upon the cam opening the admission. Both cams are slightly conical. If the normal speed is exceeded, the governor alters the position of the cones horizontally on the side shaft, the effect being that the gas valve is opened for a shorter, the admission valve for a longer period. The greater the excess of speed, the longer the latter is kept open. More of the gas and air pass into the spiral coil, less are retained to be compressed in the cylinder, and the charge will be poorer in quality and less in quantity, until the speed is reduced within normal limits. In this way the strength of the explosion and the expansion of the charge are varied by the governor, in accordance with the work done, but no ignitions are missed. The exhaust is similar to that in the Otto engine.

In the Charon engine the difficult problem of varying the compression and expansion of the charge seems to have been ingeniously dealt with, and the makers claim a considerable economy. According to them the loss of heat to the water jacket is only 19 per cent., and the temperature of the waste gases is reduced about half. Several trials have established the economical gas consumption of this motor. M. Chauveau tested a 4 B.H.P. engine in 1891, and found the quality of gas used was 20 cubic feet per B.H.P. hour. The heating value of the gas was not given. Another trial was made in 1892 by Modelski and Coustolle, upon a 25 B.H.P. engine, in which the consumption of gas was 16 cubic feet per B.H.P. hour. A later test by Witz in 1895 on a 4·7 B.H.P. engine gave a consumption of 17 cubic feet of gas per B.H.P. hour, a good result for so small an engine. A second trial on a 60 B.H.P. engine showed a consumption per hour per B.H.P. of 16 cubic feet of lighting gas, having a heating value of 598 B.T.U. per cubic foot. For details of these trials see table. A series of trials upon a 50 H.P. Charon engine were also carried out by MM. Cuinat and

Allaire in 1894. The engine had two cylinders, each 13·7 inches diameter, and 23·6 stroke, and ran at 150 revolutions per minute. The novelty of these experiments was that fifteen separate trials were made at powers rising by degrees from 16⅓ B.H.P. up to a maximum of 53 B.H.P., and for each power a corresponding indicator diagram was taken. These successive diagrams showed that when the engine was worked at a power much below normal the explosion line was almost horizontal; in other words, combustion of the charge took place. As the weight on the brake increased, the line rose until at the maximum power it became vertical, proving that explosion was almost at constant volume. The 16 indicator diagrams are all given in the original report. The following diagram, Fig. 79, shows the varying mechanical efficiencies, according to the power on the engine. It will be seen that the efficiencies rise in a regular curve in accordance with the work done. With 16⅓ B.H.P. developed on the brake, the mechanical efficiency was 52 per cent., and rose to 91 per cent. at 53 B.H.P. The next diagram, Fig. 80, gives the curve

Fig. 79.—Charon Gas Engine—Varying mechanical efficiencies according to power, on same engine.

Fig. 80.—Charon Gas Engine—Varying consumption of gas according to power, on same engine.

of varying consumption of gas, according to the B.H.P. upon the engine. At 16⅓ B.H.P. this consumption was 38 cubic feet per B.H.P. hour, at 24⅓ B.H.P. it was 26¼ cubic feet, and at 53 B.H.P. it was 17 cubic feet per B.H.P. hour, being 2½ times higher with the minimum than with the maximum power developed on the brake.

The Charon is made horizontal single cylinder from 1 to 30 H.P., and with two cylinders side by side from 16 to 100 H.P., and runs at 140 to 180 revolutions per minute. A small vertical single-cylinder type has lately been introduced, in sizes from 1½ to 4 H.P., running at 240 to 250 revolutions per minute. A large number of these engines are made in France.

Tenting.—The Tenting, made by MM. Salomon and Tenting,

at Paris, is a horizontal single-cylinder engine, simple in construction, and using the Beau de Rochas cycle. There is no slide valve. Admission of the charge is effected from a central opening below the cylinder, through which passes the rod of an automatic valve, held back by a spring. Gas and air, in proper proportions, enter the cylinder through a series of concentric holes below this valve. It is lifted by the suction of the motor piston during the admission stroke, and closes when the pressure in the cylinder, during compression and exhaust, is greater than that of the atmosphere. A valve-rod at the side of the cylinder, driven by wheels from the main shaft in the proportion of two to one, opens the exhaust valve. The centrifugal ball governor acts upon this rod through a lever. As long as the speed is normal, the lever rests against the cylinder; but if it be increased, the lever is drawn forward, and a projection upon it is interposed between the spring closing the exhaust and the valve-rod. As the exhaust valve cannot close, the pressure in the cylinder does not fall below that of the atmosphere, and the automatic admission valve is thus prevented from rising. No fresh explosive mixture enters until the speed is reduced, and the lever allowed by the governor to right itself. For sizes below 4 H.P. the cylinder is ribbed externally, and has no water jacket. The charge can be fired either electrically or by a hot tube; the engine is easier to start with the former method of ignition. It is made horizontal, in sizes from ½ to 10 H.P., and runs at 200 to 160 revolutions per minute; vertical, from 2 to 30 H.P.; and has been adapted for propelling carriages.

The various ingenious types of the Ravel engine (see p. 54) are now no longer made. M. Ravel introduced a new type in 1888, drawings of which will be found in Witz and Chauveau, but its construction has now been given up.

Forest.—Another variety of the Forest engine, described at p. 71, was brought out at the Paris Exhibition of 1889. In this motor M. Forest adopted the usual method of compression of the charge before ignition, with the Beau de Rochas cycle, giving an explosion every other revolution. There was a single horizontal cylinder, having two motor pistons, each attached to a lever and moving in opposite directions. The crank shaft above was driven by two connecting-rods, and the two cranks were 180° apart. The charge was admitted in the space between the pistons as they moved out, compressed to 5 atmospheres, and ignited electrically; the explosion forced them apart, and acted through the levers upon the two cranks. A drawing will be found in Witz. The latest type of engine is made vertical, with one piston working downwards, similar to the engines described in the oil section. For lighting gas it is constructed in sizes from 1 to 8 H.P., and runs at 300 to 180 revolutions per minute.

Niel.—The Niel, which first appeared at the Paris Exhibition of 1889, is a well-designed horizontal engine of the Otto type, with several ingenious modifications. The exhaust is a vertical lift valve; the admission gear is novel in principle and arrangement, and is worked from a side shaft geared to the main shaft by equal worm wheels. This valve shaft actuates a conical revolving valve with two apertures which, when brought to face the cylinder ports, governs the admission and ignition of the charge. Gas and air enter the cylinder through one of the ports in the valve. By the rotatory motion the charge is drawn in, usually in the proportion of one of gas to eight of air. To reduce the shock and make the engine work more smoothly, admission lasts only during two-thirds of the first forward stroke, and the charge expands slightly during the last third. Thus admission is less in proportion to expansion, but this advantage is counterbalanced by the correspondingly smaller compression. The effect of this variation from the usual cycle is seen in the indicator diagram, where the initial pressure of the gas and air falls slightly below that of the atmosphere. At the end of the return stroke the conical valve opens communication through the other port between the contents of the cylinder and the hot ignition tube. It is during this period

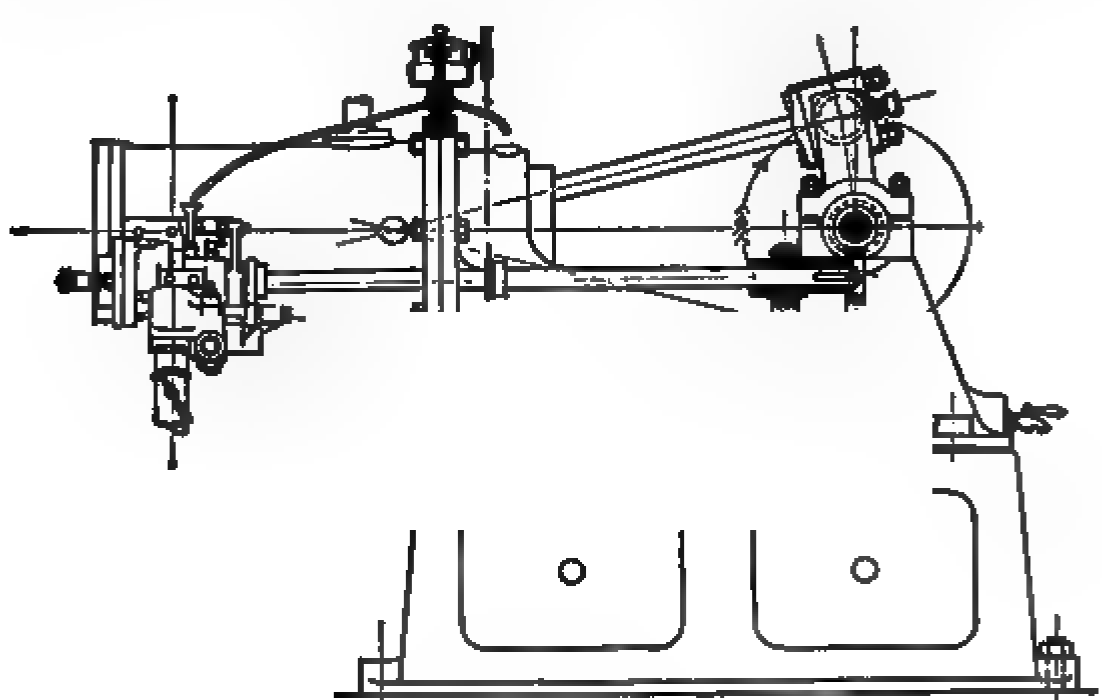


Fig. 81.—Niel Gas Engine—Sectional Plan. 1889.

of compression and explosion, that the difficulty of preventing leakage is experienced with all slide and rotating valves. M. Niel obviates it in an ingenious way, and even turns it to account. A thin metallic diaphragm in the conical valve is so arranged, that it is acted upon by the pressure of the gas in

the cylinder. Thus the valve is made to fit more closely in its socket when the pressure in the cylinder is at its maximum, the pressure on the conical part is then greatest, and leakage is minimised. The discharge of the gases does not take place through this valve, but through an ordinary vertical lift valve, opened by a lever below the cylinder, and a cam on the side shaft. Fig. 81 gives an elevation of the Niel engine, showing the side shaft and method of driving it, the conical distributor, ignition, and oiling apparatus; the exhaust valve is on the opposite side of the cylinder.

The oscillating governor consists of a T-shaped, three-armed lever, driven from an eccentric on the crank shaft. The horizontal arms carry a weight at one end, the other strikes at each revolution against a screw which can be adjusted higher or lower, and the speed thus varied while the engine is running. The vertical arm terminates in a point which, at the normal speed, opens the gas valve at each revolution. If the speed becomes too great, the vertical arm is displaced by the swing of the horizontal arms striking too soon against the screw, and no gas is admitted. The cylinder is lubricated automatically, according to the speed, from the valve shaft. An ingenious method of starting has lately been introduced. It consists of a small auxiliary pump and reservoir, into which a charge of gas and air is compressed by hand. Communication is then opened with the motor cylinder, and the products of combustion in the latter expelled by the fresh compressed mixture. The charge in the pump is fired electrically, the flame spreads, and the force of the explosion sets the flywheel in motion. Drawings of all the different parts of this engine, and a complete description by M. Auguste Moreau, will be found in *Comptes Rendus de la Société des Ingénieurs Civils*, October, 1891.

Trials.—A series of careful experiments upon a 4 H.P. nominal Niel engine was made by M. Moreau. An indicator diagram taken during the trial is given at Fig. 82. The temperatures of the gases and of the water in the jacket were determined, and nothing was omitted to make the experiment as complete as possible. M. Moreau found that, when running at 160 revolutions per minute, with a maximum pressure of 12 to 14 atmospheres, the mean consumption of Paris gas was 27·2 cubic feet per hour per B.H.P., but the engine was of an early type, and the construction has since been

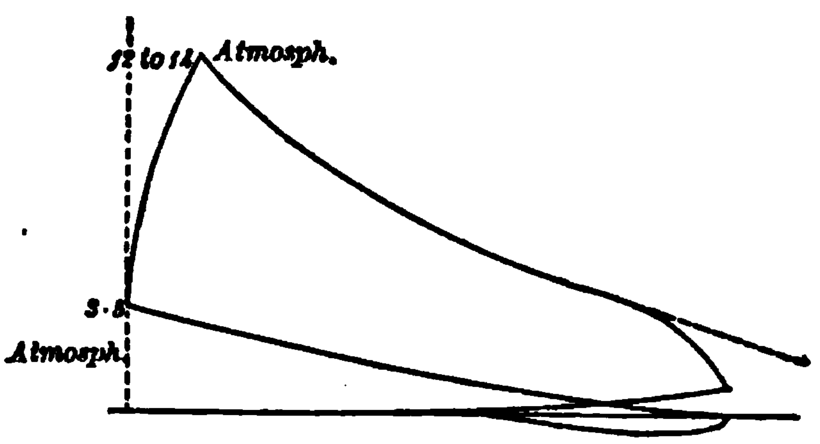


Fig. 82.—Niel Engine—Indicator Diagram. 1891.

improved. The mechanical efficiency was 75 to 80 per cent. The Niel is compact, works regularly and quietly, and has already proved one of the most successful of French motors. Hundreds of these engines are now at work in France and elsewhere, and 130 engines for powers of from ½ to 25 H.P. are said to have been sold in nine months.

The Niel is made horizontal only, single cylinder in sizes from 1 to 75 B.H.P., and runs at 230 to 150 revolutions per minute. For two cylinders side by side or opposite, it is in sizes from 60 to 150 B.H.P., and runs at 170 to 150 revolutions; in the larger engines the conical revolving valve is replaced by ordinary lift valves. Engines intended for driving dynamos run at 220 to 230 revolutions. At the Electrical Station at Rheims, the power is furnished by three Niel gas engines. Of these, two are 80 H.P., with two cylinders side by side, their cranks being at an angle of 180°; the third is a single cylinder 45 H.P. engine. At Calais, the electric light station is provided with two 80 H.P. Niel engines, each with two cylinders side by side, and at Cognac there is a similar gas plant. The Compagnie des Moteurs Niel, at Paris, have lately taken up the generation of poor gas on the Taylor system for driving their larger motors. The gas producer is made in France by M.M. Fichet and Heurtey, and is described at p. 204.

Durand and Various.—A horizontal gas engine by M Durand is still sold. It is made in sizes from ½ to 10 H.P., and runs at from 200 to 130 revolutions per minute. Electrical ignition on the system described at p. 72 is used. The **Noël**, described at p. 72, is also still made, chiefly for very small powers, for agricultural and manufacturing purposes, in sizes from ¼ to 4¾ H.P. horizontal, and ½ H.P. vertical. It runs at 320 to 220 revolutions per minute, and has no water jacket. A small horizontal engine, the **Pellorce**, made at Courbevoie, from ½ to 6 H.P., has also no water circulation for cooling the cylinder.

The Compagnie Parisienne au Gaz, who are the makers of the Lenoir, have brought out a small vertical engine of the Otto type, in sizes from ¼ to 5 H.P., running at 400 to 210 revolutions. For their 5-H.P. motors they claim a consumption of less than 23 cubic feet of gas per H.P. hour. The engines are well made and much used in Paris.

Another small horizontal engine of the usual four-cycle type is made by **Perrin** at Lyons, in sizes from ⅓ to 8 H.P. It has only two valves, admission and exhaust, driven from the crank shaft by a rod and gearing 2 to 1; the governor acts upon the gas supply, and regulates it in proportion to the work done. More than 80 of these little motors are said to be at work. The vertical **Delahaye**, at Tours, is made in sizes from ½ to 40 H.P., and runs at 300 to 150 revolutions per minute.

The **Crouan**, constructed by the Société Française du Gazomoteur, is distinguished by its compactness and small dimensions; it can be fixed against a wall or on the ground. It is difficult to imagine a simpler engine. All the valves are of the lift type, there is a ball governor, and the crank and motor shaft are enclosed. The speed of revolution can be diminished or increased in proportion to the work done, and thus the consumption of gas materially reduced. For sizes from 1 to 8 H.P. ignition is by a hot tube, for larger powers up to 40 H.P. the charge is fired electrically. The smaller types are vertical, the larger horizontal, and two cylinders, either tandem or placed end to end, are used for sizes from 4 to 40 H.P. The engine runs at 400 to 180 revolutions, and can be driven either with gas or light petroleum.

Roger.—M. Roger, of Paris, patentee of the Benz engine in France, has lately brought out a small vertical gas engine of the Otto type, with hot-tube ignition and centrifugal governor. There is no slide valve, the air valve is automatic, and the valves for admitting the gas and discharging the burnt products are worked by cams from a side shaft. The engine is made in sizes from ½ to 12 B.H.P., and runs at 300 to 200 revolutions per minute. M. Roger has especially devoted his attention to the production of oil motors for propelling road carriages (see p. 356).

Le Robuste, made by the inventor, M. Levasseur, at Évreux, is another engine which has lately come to the front. It is single cylinder, horizontal, and works with the usual four-cycle and hot-tube ignition. Like other engines which have appeared recently, it is distinguished by a circular piston valve for admitting, mixing, and firing the charge. This valve is driven by an eccentric on the distributing shaft geared 2 to 1 to the crank shaft, and is pierced by two ports and a transverse groove. At a given moment the gas admission pipe communicates with the compression space through these ports, air is drawn in from the outer open end, and both pass into the cylinder, while the piston valve moves on and closes the ports. At the end of the compression stroke the transverse groove in the piston valve opens communication with the ignition tube, and the charge is fired. The pressure of the screws holding the valve against the face of the cylinder is equalised by a diaphragm between the piston valve and the cover. The speed is regulated by a pendulum governor, consisting of two adjustable weights with a projection swinging on a pivot, as in the Simplex. If the normal speed is exceeded, the pendulum motion cannot overtake the engine, the projection misses the gas valve, and no gas enters. The hot tube is placed in the centre of the cylinder at the back, and this arrangement is said to ensure more complete ignition. The Robuste is made in sizes from ½ to 12 H.P., and runs at 200 to 160 revolutions per minute.

Brouhot.—The engine made by Brouhot & Cie. at Vierzon

(Cher), is especially intended for agricultural purposes, such as making wine, distilleries, breweries, saw, flour, and other mills, and for electric lighting; it may be driven either by gas or petroleum. It is of the ordinary four-cycle type, with a valve shaft driven by wheels from the crank shaft. The charge is fired by an electric spark from a small battery, or from a magnetiser. Gas and air are admitted into an external mixing chamber through apertures, the orifices of which are exactly proportioned. The ball governor acts upon the openings and varies the quantity of the charge, without altering its quality. The engine is made horizontal in sizes from ½ to 10 H.P., single cylinder, and 4 to 20 H.P. for two cylinders, and vertical from ¼ to 3 H.P.

The **Otto** engine is made in France by the Cie. Française des Moteurs à Gaz, horizontal and vertical, in sizes from ¾ to 120 B.H.P. According to the makers, 45,000 of these engines have been sold in Europe (including those made by the Deutz-Otto firm), and 52 patents have been taken out in France alone.

A small engine of the four-cycle type was exhibited at Antwerp in 1894 by the Société Française des Moteurs **Crébessac**, but it does not appear to have been yet placed upon the market. The charge was fired electrically, the valves were worked from a side shaft geared to the crank shaft, and the ball governor acted on the gas supply.

Letombe.—The *Letombe*, a motor having some features in common with the original Lenoir and the Griffin, has lately been brought out by MM. Mollet-Fontaine at Lille. It is a single cylinder four-cycle, double-acting engine, with variable compression and expansion. The charge is fired electrically at either end of the cylinder. The cycle is similar to that of the double-acting Griffin (see p. 110) with two explosions following each other on either face of the piston during the out and in stroke, thus giving a motor stroke per revolution. The cylinder is closed at both ends, and the exhaust ports below are uncovered by the piston at the end of each stroke. The essential novelties of the engine are a mixing chamber for the gas and air at the side of the cylinder, and two slide valves with ports driven by eccentrics from a shaft geared 2 to 1 to the crank shaft. Gas and air are admitted into the mixing chamber through an automatic valve, and pass thence into a water-jacketed passage communicating alternately with the ports in the two slide valves. When the piston has completed the exhaust stroke at one end, the port in the corresponding slide valve is brought to face the passage from the mixing chamber, and a channel leading to the cylinder. The charge is then drawn in, on that face of the piston, and compressed during the return stroke, but the slide valve is so adjusted that its port does not immediately shut off communication between the cylinder and the mixing chamber,

and part of the compressed charge is driven back into the latter. Thus the quantity retained in the cylinder, the degree of compression, and of subsequent expansion are all variable. The charge is then ignited, expanded, and driven out as usual. The pendulum governor acts upon the eccentrics driving the slide valves, and by varying their action increases compression and expansion in proportion to admission. Drawings are given by Witz.

In a single-acting type of this engine the usual four-cycle is carried out on one face of the piston only, but the slide valve and mixing chamber are retained. A projection on the governor fits at each stroke into a cavity at the end of the slide valve, and pushes it back into its original position, but if the speed is accelerated the swing of the pendulum causes the projection to miss, the slide valve remains open to both mixing chamber and cylinder, and the quantity of the charge passing to the former is increased. This engine is said to work with considerable economy, but no official tests seem to have yet been made, nor is it in the market.

Bénier.—One of the latest developments in gas engines is the introduction of motors having gazogenes attached, in which generator or power gas is made per stroke, and passes direct to the engine, without intermediate storage in a gasholder. Two of these apparatus have appeared lately in France, the Gardie and the Bénier; the former seems to be still in the experimental stage.

The Bénier generator and gas engine combined, designed by M. Bénier, is made by the Société des Moteurs-Gazogène (Fig. 83). As seen in the drawing, the engine and generator are close together, and occupy little space. The gas is produced automatically per stroke as required, by the suction of the motor piston; thus its quality is said to be always uniform, and being generated below atmospheric pressure, loss by leakage is avoided. The generator furnace consists of a cylindrical chamber lined with fire-brick, and surrounded by an outer casing, and an inner annular space. The anthracite or coke is introduced into a small closed chamber above, and falls into the furnace through a horizontal slide valve. The hollow revolving grate is circular, the ashes and clinker are withdrawn automatically, and the grate turned one quarter of a revolution per hour. In the first generator introduced by M. Bénier, the steam required for making the gas was provided by a small boiler at the top of the furnace. In the latest type the steam is generated in the grate itself from a stream of water constantly passing over the bars, and carried off at a slight pressure to the chamber shown at the right of the drawing. Here it is mixed with air entering from above, and to reduce the steam to atmospheric pressure it is first led through an open space. The suction stroke of the motor

Fig. 83.—Bénier Gas Engine and Generator. 1895.

piston next draws the steam and air to the grate through the annular space between the furnace and the outer casing. Here they are superheated, and this is said greatly to increase the efficient working of the generator. The gases from the furnace are led into the washer, shown to the left in the drawing, where they are purified, passing first through an outer annular space, and thence up the centre to the motor cylinder. The water for washing enters by a pipe at the extreme left, and is drained off below through an hydraulic joint.

The engine is of the two-cycle type. As the gas is only at atmospheric pressure, a pump is required to mix it with air, and deliver it to the engine. The two parallel cylinders, motor and pump, are shown in the drawing. The pump consists of two cylinders tandem for the admission of the generator gas and air, and is fitted with a double plunger piston, its crank being set at an angle of 90° in advance of the motor piston. The pump piston first draws the gas through the generator as described, then air from the atmosphere, and sends them on to the mixing chamber at the back of the motor cylinder. The exhaust is in front, the holes being uncovered by the motor piston when it has passed through five-sixths of its out explosion stroke, and closed again at one-sixth of the return stroke. During the remaining five-sixths of the instroke the charge is compressed in the motor cylinder. As, however, the pump is slightly in advance of the motor piston, it is necessary to prevent the escape of part of the fresh gases through the exhaust. The pipe conveying the generator gas to the pump has a valve admitting air as well as gas, and during the last part of the pump stroke a small quantity of air is drawn in, delivered first into the motor cylinder, and escapes through the exhaust. As the ports are covered immediately after by the motor piston, the regular charge is retained in the cylinder. The quantity of gas admitted is regulated by the governor, and electric ignition is used.

Two good trials of a Bénier gazogene motor were made by Prof. Witz at Lille in 1894. In the first, English anthracite was used, the calorific value of which was taken at 14,400 T.U., and the consumption per B.H.P. of pure coal, deducting cinders, was 1·4 lbs. The second trial was made with broken gas coke, containing 10 per cent. ash and 6·5 per cent. water, the heating value of which was estimated at 12,240 T.U., and the consumption was 1·6 lbs. per B.H.P. The heat efficiency of the engine and generator worked with coke was 12·4 per cent., and with anthracite 11·3 per cent. This lower result was attributed by Witz to the size of the generator, which was too large for the engine. For further particulars see table of Trials.

The Bénier engine is made in sizes from 6 to 40 H.P. with one cylinder, and 30 to 150 H.P. with two cylinders, and runs at 160 to 120 revolutions per minute. Although a new engine,

the makers have constructed 20 in a few months. Prof. Witz has a high opinion of it, although he considers that its low mechanical efficiency is due to the work devolving on the engine of generating, drawing in, and compressing the gas and air.

CHAPTER XIII.

GERMAN GAS ENGINES—THE KOERTING, ADAM, AND BENZ.

CONTENTS.—Koerting-Lieckfeldt Original Type—Koerting Type of 1888—Ignition—Governor—Horizontal Motor—Adam—Four-Cylinder Type—Benz.

Koerting.—Next to the Otto, no gas engine is so popular or so extensively made in Germany as the Koerting. It was first brought out as a vertical engine in 1879, and may, therefore, claim to rank as an historical motor. Since then many improvements have been introduced, and the mechanical details are still undergoing alteration.

The principal advantages of vertical gas engines consist in the smaller floor space occupied as compared with horizontal motors, and their lesser weight. For this reason, various attempts have been made to utilise the vertical type, one of the most successful of which was the Koerting-Lieckfeldt. For smaller engines and marine work it is often used, but there is always a good deal of vibration, and it cannot be employed for larger powers.

In the original engine brought out by MM. Koerting and Lieckfeldt a novel method of ignition by propagation of flame in a conical tube was adopted. The principle on which it was based may be studied in the drawing (Fig. 85, p. 168), but in all the present engines ignition by hot tubes made of porcelain has been employed. The method of regulating the speed, still used in most of the Koerting engines was, at the time of its introduction, a novelty. If the normal number of revolutions is exceeded, the governor acts upon a lever, one end of which keeps the exhaust valve open, while the other holds a return valve in the mixing chamber closed. As the gas and air are admitted through an automatic valve lifted by the vacuum in the cylinder, no charge can enter while the exhaust is open. The discharged products are drawn in at the next stroke, and this continues till the speed is reduced, and the governor releases the exhaust valve.

There have been several distinct periods in the construction of

the Koerting-Lieckfeldt engine. In the original vertical type of 1881, an auxiliary pump was introduced, the four operations of admission, compression, explosion plus expansion and exhaust, were divided, as in the Clerk engine, between the two cylinders, and an impulse obtained at every revolution. There were two cranks, motor and pump, working upwards on to the same shaft. The mixture expanded in the motor cylinder, doing positive work on the piston, while the pump drew in a fresh charge. If the speed was too great, the ball governor opened communication between the pump and a reservoir, into which part of the compressed mixture was driven, and at the next stroke the pump drew in a smaller charge. The construction of this engine, drawings of which will be found in Schöttler, has been given up, and the style of the firm changed. It is now known as Koerting Bros., of Hanover, and the present engine is called the Koerting.

Type of 1888.—In this motor, still used for small powers, the four-cycle of Beau de Rochas was adopted, giving only one working stroke in four. Fig. 84 gives a sectional elevation and Fig. 85 a sketch of the method of ignition. In Fig. 84, A is the motor cylinder, P the piston, *d* the connecting-rod, working direct on to the crank shaft K. All the valves, with the exception of the automatic admission valve, are worked from a rocking shaft, *u*, containing two levers. The crank shaft carries at the end a wheel, *e*, gearing into another below it, *f*, of twice the diameter. With the latter revolves a second shaft, *c*, carrying two cams, S and S_1. These cams work, S_1 through the lever T_1 on the valve rod R_1, and the ignition tube I, S through lever V on the rod R, lifting the exhaust. Both valves are opened once in every cycle by the cams, and closed by springs.

I is the ignition chamber, E the exhaust valve; the air enters at H from the base of the engine, the gas above it, and both mix at *o*. The automatic valve N is lifted by the pressure, and the gas and air are thoroughly combined before passing on to the cylinder. As soon as the down stroke of the piston compresses the gases into the ignition chamber, the valve M rises to prevent the flames from shooting back into the mixing chamber. Fig. 85 gives a sketch of the method of ignition. A small chamber communicating with the motor cylinder is in two hollow divisions, the lower *b* fitting into the upper *d*. The larger *d* has an opening at the bottom, *h*, and a transverse groove *o* above, opposite to which is the external flame B. The lower piece *b* usually rests upon the support *d'* and between it and *d* is a small longitudinal space or aperture, *m*, forming a continuation of *h*. Enclosed within *d* and *b* is a cone-shaped tube in two parts; the upper *r* is solid, the lower *s* is hollow, and tapers towards the bottom, where it communicates during the compression and explosion of the gases with the motor cylinder through *a*. At other times the connection between the ignition

chamber and the motor cylinder is shut off. *s* and *d* are the stationary, and *r* and *b* the moving parts. Before the end of

Fig. 84.—Koerting Gas Engine—Sectional Elevation. 1888.

the down compression stroke, the pressure of the gases drives up b, closing the passage m, while the solid cone r is lifted by the valve-rod R_1 (Fig. 84). The lower piece having left its support d' the compressed gases rush up the narrow end of the cone s, and ignite at the flame B through the groove o; r is now driven down by the cam on the auxiliary shaft and the valve-rod R_1, and the part b descends, leaving the passage m free. The mouth of the cone being suddenly closed, while the compressed gases are still entering from below, the flame shoots downwards until the pressures are equalised. The ignited gases rush out through m and h, and fire the remainder of the charge. The pressure of the explosion firmly closes the return valve M.

Fig. 85.—Koerting Ignition Valve. 1881.

Governor. — The exhaust valve E is worked by the rod R, in the same way as the ignition valve by R_1, except when acted upon by the governor, as shown in Fig. 86. Upon the shaft c is a weight, n, revolving at the same speed as the counter shaft round a fixed point, and held in position by a spring, s. If the speed is normal, the weight does not interfere with the working of the valve, which is regularly opened once in every revolution of c by the cam S. But if the proper speed be exceeded the weight rotates too rapidly, projects outside the wheel, and pushes forward a bell crank, l, carrying a notch at q. This notch catches in a projection on the lever v, at the moment when it is pushed down by the cam S; the lever v and rod R are raised, and the exhaust valve lifted. At the same time the opening of the exhaust valve raises the left arm of a rocking lever, G (Fig. 84), and the other arm holds the return valve M closed until the speed is reduced. The jacket water is cooled in pipes by circulation of air, a system adopted in other motors. Fig. 87 gives a sketch of the vertical Koerting engine.

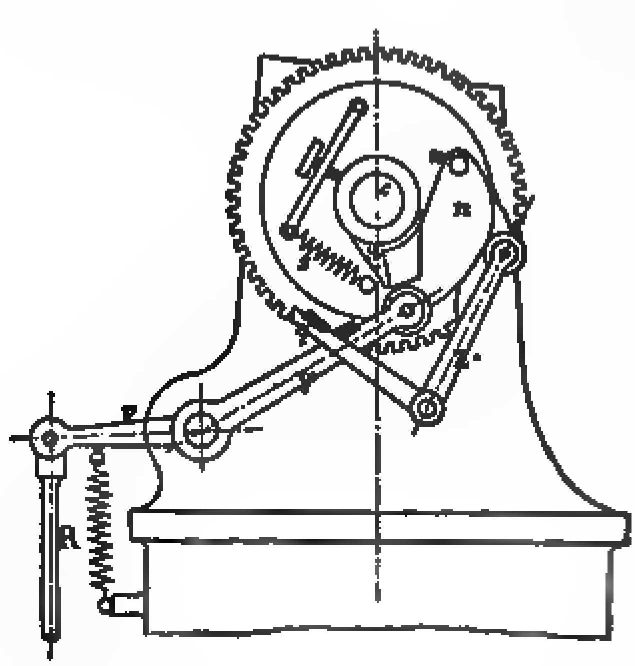


Fig. 86.—Koerting Governor—Elevation.

Horizontal Type.—MM. Koerting have also brought out a horizontal motor of the usual four-cycle type (see Fig. 88). In this engine hot-tube ignition is used with a Bunsen burner. During the compression stroke the tube communicates through a valve with the outer air, discharging the products of combustion. The velocity of the gas entering the ignition chamber is said to be so great, that the flame does not spread back into the cylinder until the outer valve is closed, when it shoots forward, igniting the remainder of the charge. The valves resemble those of the vertical engine, except that they are worked by eccentrics on the crank shaft; in the latest types these are replaced by cams worked from an auxiliary shaft. There are three valves, the automatic gas and air valve, the admission valve to the cylinder, and the exhaust. A lever acted upon by the governor works, as already described, between the exhaust and admission valves. There is also an arrangement to prevent the eccentrics on the crank shaft from opening the valves at every revolution, instead of every other revolution. Fig. 88 gives an elevation of this horizontal motor. The Koerting engines are made vertical from $\frac{1}{2}$ to 6 B.H.P., horizontal from 2 to 30 H.P.

Fig. 87.—Vertical Koerting Gas Engine. 1893.

MM. Koerting now make a speciality of their horizontal engines for driving dynamos; a two-cylinder, single acting tandem type, with the usual side shaft for working the valves, is shown at Fig. 89. The governor is arranged to vary the strength of the charge within narrow limits. The admission valve carries a series of levers and a slide. At ordinary speeds it is held open during the whole of the forward stroke, but with the slightest variation in the number of revolutions the valve is closed earlier, the time of closing being regulated by the movement of the balls. A certain portion of the charge is always admitted, even when the engine is running empty. The ignition valve is connected by a link motion to the eccentric governing the admission, and usually begins to open when the

engine crank is 20° before the inner dead point. When the slide is in its lowest position, and only a small charge is ad-

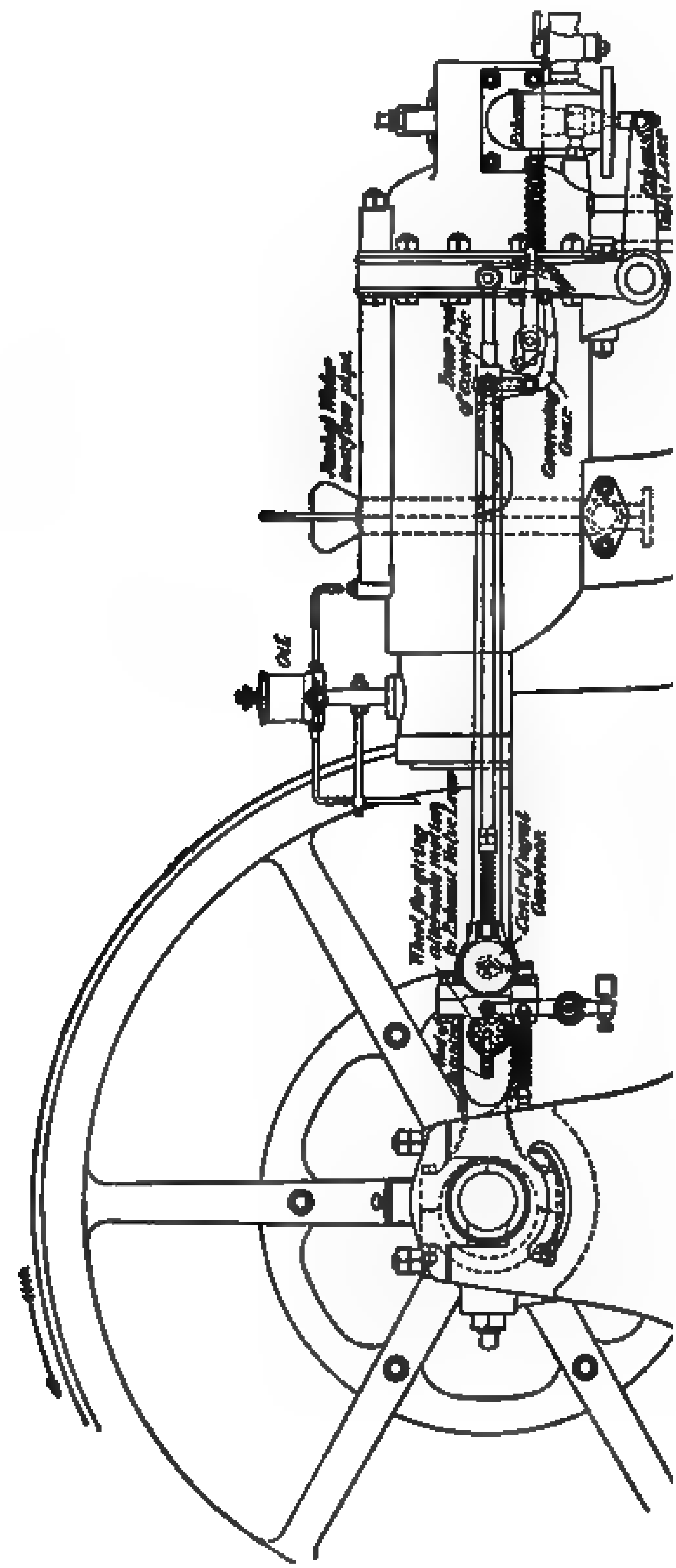


Fig. 88.—Koerting Horizontal Gas Engine - Elevation. 1898.

mitted, a lever is shifted, and earlier ignition is obtained. By this means even a weak charge may be ignited with certainty. These engines, coupled direct to dynamos also supplied by the

Fig. 89.—Tandem Gas Engine (Koerting). 1895.

firm, are made from 2 to 120 H.P., single or double cylinder, and run at 240 to 120 revolutions per minute. They are

intended to be driven either with lighting gas, benzine, or power gas.

A large number of tests have been made on Koerting engines, including several on the earlier types. Trials were made at Hanover in 1890 by Prof. Fischer on a 20-B.H.P. engine, giving a consumption of 25 cubic feet of German gas per B.H.P. hour. A later trial by Dr. Epstein in Frankfort in 1893 on a 35-B.H.P.

Ign

Fig. 90.—*Adam* Gas Engine—Sectional Elevation. 1888.

engine showed a consumption of 19 cubic feet of gas per B.H.P. hour. Details of these and of other trials will be found in the table at the end of the book.

MM. Koerting have not been behind others in using power gas, and all the motive force required for their works near Hanover is furnished by it, the engines developing a total of 300 H.P. Another gas plant is at Sestri Ponente in Italy, where two 36 H.P. Koerting engines are driven by this gas.

Adam.—The Adam vertical gas engine, constructed by the Maschinen-Bau Gesellschaft at Munich, from the patents of Mr. G. Adam, resembles the Koerting in many respects. Ignition is effected by propagation of flame; the governor acts on the exhaust valve, and the products of combustion are re-introduced into the cylinder, instead of a fresh charge, if the speed be too great. The makers of the Adam, however, claim these details as the result of independent invention. The smaller sizes have one, and the larger types two cylinders, as shown in Fig. 93.

The Adam is of the usual four-cycle single-acting type, and there is one working stroke for every two revolutions. Fig. 90 gives a sectional elevation of a single-cylinder motor. The lift valves are worked in the same way as in the Koerting, by a small auxiliary shaft K_1 driven from the crank shaft K by spur wheels two to one. The organs of admission, distribution, ignition, and exhaust are arranged side by side, and shown to the left. Gas and air are admitted into the mixing chamber, the gas from above, the air from below. The admission valve is conical, and the stream of gas is directed into a chamber, where it is thoroughly mixed with the air. Another automatic valve then lifts to admit the mixture through the wide passage *b* at a certain pressure into the cylinder A with piston B. The constructors lay much stress on the width of the passage *b*, and the delivery of the gas and air at a pressure of several atmospheres into the cylinder. This pressure completes the thorough mixing of the charge, and the makers declare that, without it, the high explosion pressures and consequent increase in work done on the piston cannot be obtained. If the charge is perfectly mixed, an ignition pressure of 10 to 18 atmospheres is possible. The gases, already compressed, being drawn into the cylinder by the up stroke of the piston, the next down stroke drives them into the ignition chamber H, where they are ignited and force up the piston; the second down stroke discharges the products through the exhaust at E. The ignition-rod S and exhaust valve-rod S_1 are driven from the auxiliary shaft K_1, and are kept in position by springs, *t* and *t'*.

Although the principle of ignition by propagation of the flame has been applied to the Adam engine, the details are worked out in an original manner. The ignition chamber consists of a hollow tube or cylindrical valve, V, enclosed within another in which works a small vertical piston, *p*. The bottom of the outer tube is pierced with holes passing through into the passage *b* and the compression space of the cylinder; the top is open, and communicates with an external flame, B. At the moment of ignition, the compressed gases from the motor cylinder enter the tube through the passage *b* and the holes, while the small piston *p* is in its highest position. The down stroke of the motor piston drives them up the tube till they meet the flame at the opening

d, and are ignited. The valve piston now descends, closes the opening *d*, thus shutting off communication between the flame B and the ignited gas in the tube, and drives down the cylindrical valve. A small orifice at the bottom, opening into the compression channel *b*, is thus uncovered, and the flame, cut off from upward progress, shoots through it into the remainder of the compressed gases, and rapidly ignites the whole (compare Fig. 85).

The speed is regulated by the ball governor, which keeps the exhaust valve open a shorter or longer time. The governor G, shown in Fig. 90, at the top of the engine, actuates the valve-rod S_1. The counter shaft K_1 carries two cams of different sizes for working the exhaust, and a hollow for the ignition valve. The two valve-rods end in a roller, *e*, just below the counter shaft. When the hollow in the cam is brought round to the rod S, working the small valve piston *p*, the rod is allowed to rise, and with it the piston, and the gases ignite. During the remainder of the revolution the rod and piston leave the hollow, and are driven down, and no ignition of the gases at the external flame B can take place. The exhaust valve-rod is usually opened once in every revolution of the counter shaft by the smaller cam. But if the speed be too great, the balls of the governor rise, and shift the roller *e* from the smaller to the larger cam. Thus the exhaust remains open during half a revolution of the shaft K_1, or while the piston makes one down stroke (exhaust), and the next up stroke (admission of the charge). Meanwhile the automatic admission valve cannot rise, being held in position by a strong spring. The suction of the piston failing to draw in a fresh mixture, the gases of combustion are re-admitted, and continue to enter till the speed is diminished, and the roller released and transferred to the smaller cam.

The constructors of the Adam have also introduced a twin-cylinder vertical engine for larger powers. A 25 H.P. motor of this kind was shown at the Munich Exhibition in 1888; and another of 30 nominal H.P., with four cylinders, at the Frankfort Electrical Exhibition in 1891. The latter was of the same type as the twin-cylinder engine, with double the number of cylinders. Fig. 91 gives a view showing a sectional elevation, Fig. 92 a plan, and Fig. 93 a section through one pair of cylinders. The cylinders are placed diagonally to each other, and the makers consider this disposition advantageous; the centre of the axis of each is in line with the centre of the crank axis. The four pistons work opposite each other in pairs on to two cranks 180° apart, and one crank shaft; the up stroke of one of the pair of pistons is always more rapid than the corresponding down stroke of the other. Thus the engine, instead of being a four-cycle, is virtually a two-cycle motor, and there is an explosion, beneath one piston of each pair, every time it passes the dead point. The valves for admission, ignition, and exhaust are the same as in

the single-cylinder engine, and are ranged at either end, at right angles to the cylinders. Figs. 91 and 92 show the arrangement of the parts; the flywheel is in the centre, with two cylinders on each side. The admission valve is automatic, the air enters

Fig. 91.—Adam Twin-Cylinder Gas Engine—Side Elevation. 1887.

from the base of the engine, through holes, into the seat of the valve, the gas from the side. The distribution valve, Fig. 91, is lifted from its seat at each stroke of the piston, to admit the thoroughly mixed charge into the cylinder. On the left of the same drawing is shown the ignition valve and rod, and the method of firing the charge, which is similar to that in the single-cylinder engine. The ignition and exhaust valves are worked by rods from the small counter shaft; the latter runs at right angles to the crank shaft, from which it is driven by wheels geared in the usual way. The counter shaft carries cams, acting upon rollers, at the top of the exhaust and ignition valve-rods. There is a ball governor to each pair of cylinders, the action of which is the same as in the single-cylinder engine. The Adam

engine is made vertical, in sizes from 1 to 150 H.P., with one, two, or four cylinders, and runs at 150 to 200 revolutions per minute. In twin-cylinder engines intended for driving dynamos, the action of the governor is delicately regulated. If the normal speed is exceeded, the governor holds open the exhaust valve of one cylinder only, while the other continues working. Thus the cylinders are not cooled as much as if the working were suspended in both. The action is automatic, and variations up to 70 per cent. of the total load can be met without causing the light to fluctuate.

Fig. 92.—Adam Twin-Cylinder Gas Engine. Fig. 93.—Adam Engine.

The most important trial upon an Adam gas engine was carried out by Professor Schröter, of Munich, in 1889. The twin-cylinder engine tested was of 11 B.H.P., making 174 revolutions per minute, and showed a gas consumption of 31 cubic feet per B.H.P. per hour. Other and later experiments made upon different sizes of engine up to 12 H.P. gave better results. Details are given in the Table of Trials. At Nuremberg, in 1888, in an 11·72 B.H.P. engine, the consumption was 27 cubic feet of gas per B.H.P. per hour, including the external flame. The most recent experiments with a 6 B.H.P. engine show a consumption of 23 cubic feet of German lighting gas per B.H.P. per hour.

Benz.—One of the best designed of German engines was the Benz, patented in 1884, and constructed by the Rheinische Gas-Motoren Fabrik at Mannheim. In it the problem was again treated, how to obtain a motor impulse per revolution, without

the additional complication of a second pump cylinder. The loss of power and want of regularity in four-cycle engines, giving an explosion only every two revolutions, was thus avoided. In the opinion of Professor Witz, the difficulty was more completely and satisfactorily solved in this than in any other engine. The chief novelty was the introduction of a charge of compressed air, to aid the piston during its return stroke, in driving out the products of combustion. This arrangement was found to work well, but it entailed a small pump to compress the gas, and a separate receiver, from which the compressed air was admitted into the cylinder.

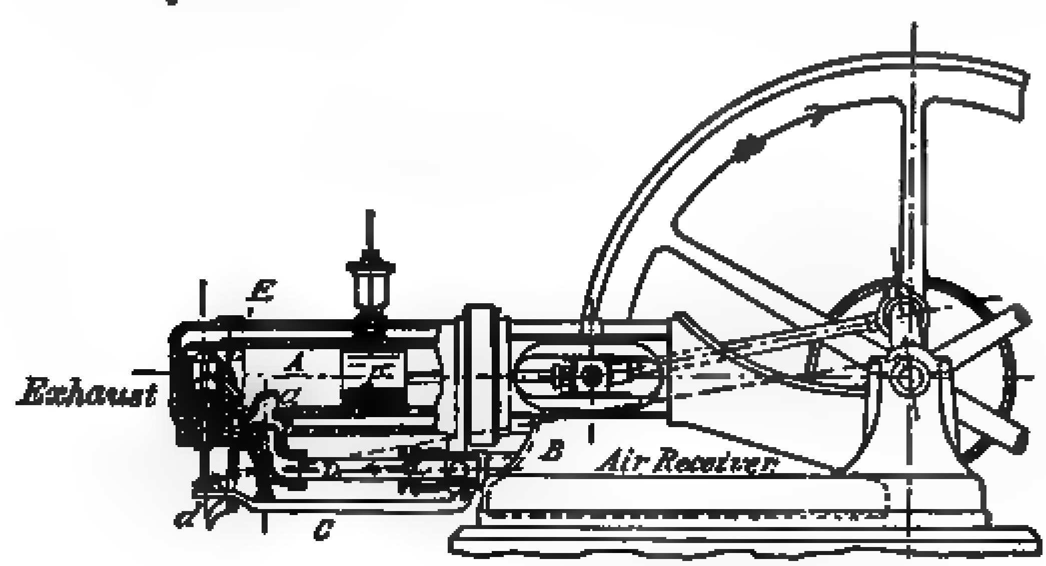


Fig. 94.—Benz Gas Engine—Elevation. 1885.

Exhau

Fig. 95.—Benz Gas Engine—Plan.

Fig. 94 gives an elevation and Fig. 95 a plan of the Benz engine. A is the horizontal motor cylinder closed at both ends, in which the piston P works, A_1 the small gas pump with plunger piston P_1. The air receiver in the base of the engine B is shown at Fig. 94, and D is the pipe through which the compressed air passes to the cylinder. S is a slide valve, worked

12

by eccentric *g* on the crank shaft, through which and the port *m* the air is drawn, in the first instance, into the front part of the cylinder. During the next forward stroke, the side of the piston next the crank compresses it into the receiver below, from whence a charge of compressed air enters the back of the cylinder through D and the lift valve *a*. E is the exhaust valve, *c* the electric ignition wires. The two valves *a* and E are worked from the crank shaft by an oblique rod indicated by dotted lines in Fig. 94, a lever, C, and a small oscillating cam, *d*, which at a given moment pushes up the valves from their seat. The piston P_1 of the gas pump is fixed by a transverse bar, *l*, to the cross-head, and moves with it. The gas is admitted into the pump A_1 through a valve connected to the governor, which raises it for a longer or shorter time, according to the speed. The return stroke of the pump compresses the gas into the motor cylinder, through a passage and the lift valve *f*. This valve is held down on its seat by a spring, except at the end of the pump stroke, when it is pushed up by the projection *g*, acted upon by the lever *n* and eccentric *h* on the main shaft. For the compression of the air into the receiver the front part of the motor piston is utilised. Air is drawn in during the return stroke at the end of the cylinder nearest the crank, and compressed by the next forward stroke into the receiver, an arrangement which has been described in several other engines. This air is intended to act as a cushion in front of the piston, to keep the cylinder cool, and deaden the shock of explosion. The electric ignition is obtained from a small dynamo, and a Ruhmkorff coil. The mass of the engine is connected to the negative pole, the wires are insulated in a porcelain rod which projects into the cylinder at *c*, and contact between the points is established by levers working from the crank driving the exhaust and air injection valves.

It should be noted that this cycle utilised the two sides of the piston, a constant pressure was maintained in the air chamber, and the indraught of fresh air certainly helped to keep the cylinder cool. The whole of the forward stroke being spent in expansion, and the discharge, admission, and compression of the gases being carried out during the return stroke, great expansion was obtained in proportion to compression. The manufacture of these two-cycle engines has, however, now been given up in favour of the cheaper and almost universally used four-cycle type. A trial on the Benz engine will be found in the table.

CHAPTER XIV.

OTHER GERMAN GAS ENGINES.

CONTENTS.—Daimler—Dürkopp—Dresdener Gas-Motor—Kappel—Lützky—Berliner Maschinen-Bau Motor—Sombart—Capitaine—Various small Engines.

Daimler.—This engine is constructed by the Daimler Motoren Gesellschaft at Cannstadt, near Stuttgardt; the French makers are MM. Panhard and Levassor at Paris, and it is sold in England by the Daimler Motor Syndicate, and in America by Messrs. Steinway & Sons of New York. One of these engines was shown at the Paris Exhibition of 1889. It has several novel and interesting features, the chief of which are its great speed, the absence of a water jacket, and the purity of the charge, due to the complete expulsion of the products of combustion. By employing high speeds and thoroughly cleansing the cylinder of the burnt gases, the inventor aimed at producing a light, but powerful engine. The original motor had one cylinder; the latter type, as now made, is vertical with two cylinders. It was introduced in 1889, and is better designed and more economical than the first.

This Daimler motor differs from most others because all the organs, even the flywheel, are enclosed in a metal casing, to protect the parts from dust, to keep in the oil, and to serve as a reservoir, into which air is introduced and compressed by the action of the piston. The horizontal shaft is below, at right angles to the axis of the cylinders, and passes through the centre of the casing. There are two cylinders and two pistons, placed diagonally at a slight angle above the crank shaft, and working down through two connecting-rods upon two cranks. The explosion in one cylinder is sufficient to drive both cranks through one revolution. The engine is of the four-cycle type, but the operations of admission, compression, explosion plus expansion, and exhaust are performed alternately in each cylinder. The gases are admitted during the down stroke of the one piston, and simultaneously expanded by the down stroke of the other, which is the working stroke. The next up stroke compresses the charge in one cylinder, and expels the burnt products in the other. Thus there is an explosion and a motor impulse in one or the other cylinder for each revolution, and a complete cycle is carried out in each cylinder during two revolutions. The charge is very rich, the products of combustion being completely expelled at each stroke. The

flame spreads rapidly through the pure mixture, and the speed of propagation is even greater than the piston speed. These effects are obtained by means of two special air admission valves. One of these is in the centre of each piston, and is lifted by forks during the up stroke, closing when the pressure above is greater than that below. The other air valve is at the side of each cylinder, and opens automatically to admit air from without, as soon as the air in the reservoir has been exhausted through the piston valves. As this reservoir fills, the pistons descend, making their down stroke, and compressing the air below them. Having reached their lower dead point, they begin to return,

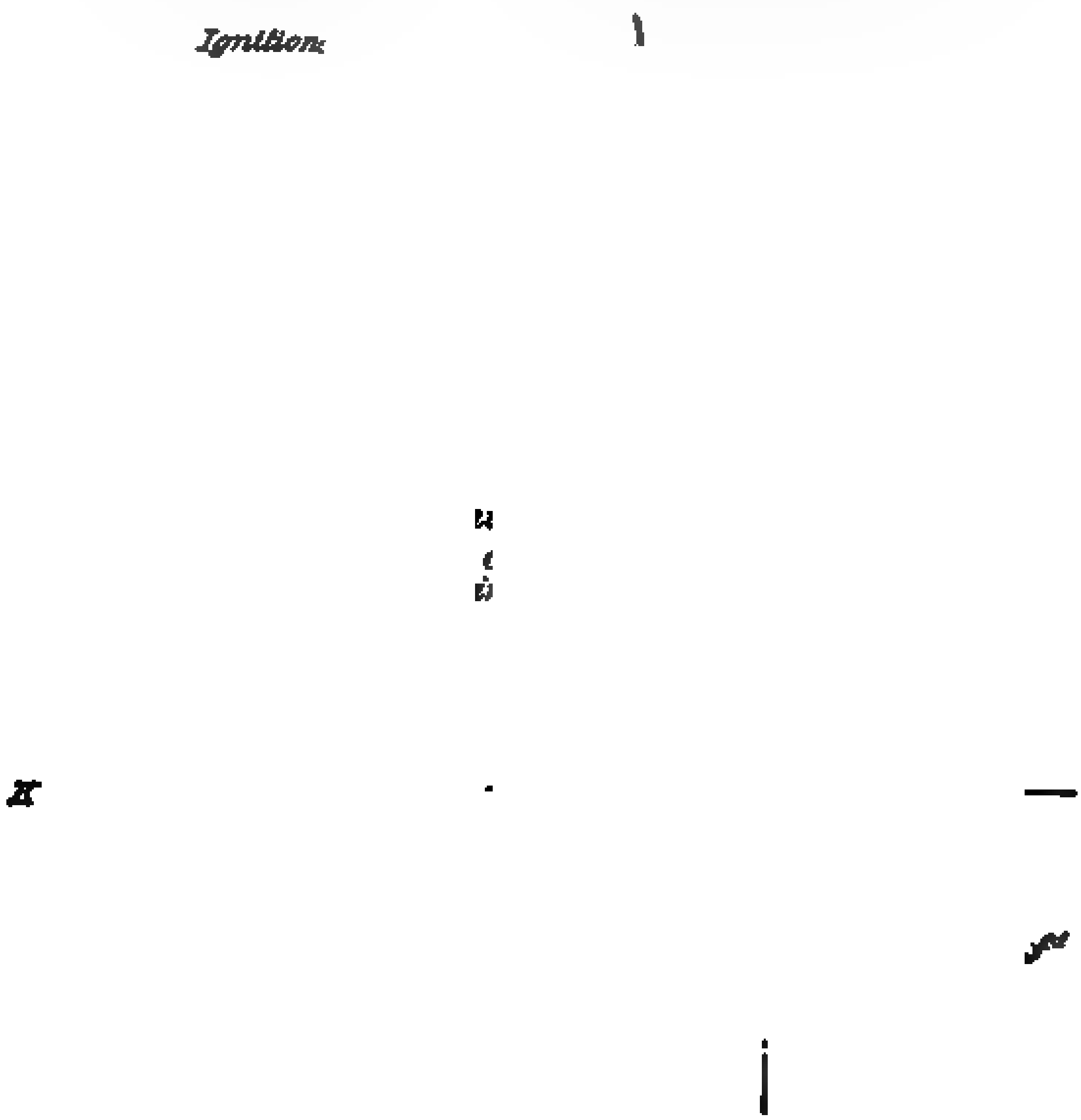


Fig. 96.—Daimler Engine—Section. 1888.

Fig. 97.—Daimler Engine—Elevation.

the products of combustion being behind the one, and the fresh charge behind the other. At this moment the piston valves are lifted. In one cylinder the air from below mingles with the fresh charge, and is further compressed; in the other it drives out before it the products.

Figs. 96 and 97 show the arrangements of the parts. A and A_1 are the cylinders, P and P_1 the motor pistons, C and C_1 the two cranks, K is the crank shaft, and B the cylindrical casing in which the cranks are enclosed, resting on brackets; c and c_1 are the connecting-rods. At O, Fig. 96, is the automatic valve, opening to admit external air into the reservoir below the pistons. The two piston valves V and V_1 are lifted at each up-stroke by two forks, I and I_1, to admit air from the base or reservoir into the upper part of the cylinder. The admission, ignition, and exhaust valves are enclosed in a valve chest, S, at the top of each cylinder. Admission is effected through an automatic valve, L, which rises as soon as the exhaust has closed and a vacuum is formed, and the gases pass to the cylinder through a wide passage, *m*. In the next up compression stroke the mixture is driven into the hot ignition tube J and fired, and during the exhaust stroke the gases are discharged through the same passage, and through the exhaust valve E. In the admission and firing of the charge the engine does not differ much from others of the four-cycle type, but it has neither counter shaft nor eccentric. Admission and ignition are both automatically obtained by the suction and compression of the piston, and the exhaust is opened by a vertical valve-rod, R, parallel to the cylinder.

As in many engines having an automatic admission valve, the speed in the Daimler is regulated by the governor acting on the exhaust valve, keeping it closed a longer or shorter time. As long as it is not opened, the pressure in the cylinder, increased by the compressed air from the reservoir, is sufficient to prevent the admission valve from rising, and admitting a fresh charge. The exhaust rod carries a lever with two arms, r' and r'', oscillating round the fixed point r. A small projection, t, on the rod R fits into a groove, s, on the disc of one of the cranks, and as the crank rises it lifts the valve. This groove is so contrived that it only meets the projection on the valve-rod, and opens the exhaust, once in every two revolutions of the crank. Each time this occurs, the longer of the two arms reaches and opens the exhaust valve. If the speed exceeds the normal limits, the governor G on the crank shaft pushes up a second lever, n, terminating in a projection, n_1, Fig. 96. The projection catches in the arm r_1 of the lever, as seen in Fig. 97, and holds it down. The exhaust valve not being opened, the products of combustion remain in the cylinder, and no fresh charge is admitted until the speed is again reduced, and the arm of the lever released.

The speed of this engine is from 450 to 700 revolutions per minute, and for the power obtained it occupies a relatively small space. The 1 H.P. engine shown at the Paris Exhibition of 1889 made 700 revolutions per minute, and was 2 feet 5 inches high. The charge of cool air introduced at every down stroke into each cylinder helps to prevent overheating. The Daimler

has not hitherto been made for larger powers. For small motors, which generally consume more gas, it is said by the makers to require about 35 cubic feet gas per I.H.P. hour. It is a convenient little engine, light and easily handled, and powerful for its size, on account of the great speed at which it runs. As the parts are not easily accessible, and the flywheel cannot be turned by hand to start the engine, a handle is fixed to the outside to set it in motion. This engine is also made vertical, for 1, 2, or 4 parallel cylinders, in sizes from ½ to 10 H.P. nom., and runs at 750 to 480 revolutions per minute, but it is more generally used with oil. No official trials appear to have been published.

Dürkopp.—The Dürkopp gas engine, made by the Bielefelder Nähmaschinen Fabrik, is another four-cycle motor. In the vertical type the cylinder, and the admission, ignition, and exhaust valves are in the lower part, and the connecting-rod works upward on to the crank. The motor shaft is above, and carries on one side the flywheel and driving pulley. On the other is a vertical side shaft worked by wheels 2 to 1. The valve chest is at the bottom, and all the valves are driven by cams. Air and gas are admitted at the side, and pass into the mixing chamber through a valve lifted by a cam upon the side shaft. The same cam forces up a lever opening the exhaust. The gases of combustion are discharged through an exhaust valve made in two parts, larger and smaller. To obtain a more quiet discharge, part of the gases are allowed to escape through the smaller valve, before the main exhaust valve opens. Ignition is by a hot tube, the opening of which is uncovered by a cam lifting a small valve-rod. The governor is also placed on the counter shaft. The levers connected to the gas admission valve are opened by a cam once in every revolution of this shaft, but if the normal speed be exceeded, the balls of the governor rise, and shift the cam out of position. The gas valve remains closed, wholly or partially, until the speed is reduced, and the balls fall. The engine is made single cylinder, vertical, in sizes from ¼ to 12 B.H.P., and a horizontal type has also been introduced, with one or two flywheels, from 1 to 30 B.H.P. single cylinder, and 4 to 60 B.H.P. for two cylinders. The consumption of gas is said to be from 23 to 35 cubic feet per I.H.P. per hour, and the engine runs from 250 to 150 revolutions per minute, according to size. In estimating the economical working of foreign engines by their consumption of gas, it must not be forgotten that town gas on the Continent has generally a lower calorific value than English gas.

Dresdener Gas-Motor.—The gas engine brought out by the Dresdener Gas-Motoren Fabrik (Hille's patent) is a compact and well-made engine, single acting, both vertical and horizontal. About 600 engines are sold annually, and the makers claim (1895) to have constructed about 2,500. Like many engines

which have appeared since the expiration of the Otto patent, it adheres very closely in working details to that type. It has the usual sequence of operations, admission, compression, explosion plus expansion and exhaust, each occupying one forward or return stroke, and there is one explosion for every two revolutions. The piston-rod and connecting-rod work direct on to the crank shaft. A slide valve at the side of the cylinder, acted on by a valve-rod from a counter shaft, effects the admission of the gas and air and governs the hot-tube ignition, in the larger engines. The counter shaft is driven from the crank shaft in the usual way, by wheels 2 to 1. The exhaust valve below the cylinder is opened by levers, and closed by a spring, as in the Otto; it is worked from the counter shaft by a separate valve-rod. For small powers, from ½ to 6 H.P., these engines are made vertical, with a pendulum governor, and run at 180 to 230 revolutions per minute. For powers from ½ to 60 H.P. a horizontal single-cylinder type, making 120 to 180 revolutions per minute, is used, with a centrifugal governor. Where great regularity is required, as for electric lighting, the engines have two cylinders, are made in sizes from 3 to 60 B.H.P., and run at 150 to 200 revolutions per minute. Trials on the Dresdener engine have been made by Professors Schöttler and Levicki. The former tested a 16½ B.H.P. engine at Dresden, and found the consumption to be 24 cubic feet of gas per B.H.P. hour Professor Levicki experimented on a 6·8 B.H.P. engine, the consumption in which was nearly 26 cubic feet of town gas per B.H.P. hour, and the mechanical efficiency 90 per cent. See Table of Trials.

Kappel.—The Maschinen Fabrik Kappel, at Chemnitz, Saxony, have introduced a horizontal gas engine, similar in many respects to the Otto. The exhaust in this motor is opened by two projections and a roller worked from an eccentric on the valve shaft; the second projection opens the exhaust at starting, during the compression stroke. Air and gas are admitted through lift valves, and ignition, contrary to the usual practice, is by a small slide valve at the side of the cylinder, which performs no other function than to uncover the hot-tube port. The ball governor is driven from the valve shaft, and controls an eccentric which actuates the ignition slide valve. In engines intended for driving dynamos the rod opening the gas valve is so adjusted to the governor, that when the latter is in its lowest position the largest quantity of gas is admitted, and the amount diminishes as the balls of the governor rise, till it is only one-third of the original. At a still greater excess of speed, the gas valve remains closed. Sometimes a spring governor acting on the gas admission and air valve-rods is used. The spring is deflected by two screws more or less according to the speed, and by altering the position of the screws the speed of the engine

can be increased from 100 to 175 revolutions per minute. The engine is made horizontal only, single cylinder, in sizes from $\frac{1}{2}$ to 60 H.P., two cylinders 10 to 120 H.P., and runs at 200 to 140 revolutions per minute. It was tested at the "Fachaustellung," in 1891, and gave 6·25 H.P. on the brake, with a consumption of 26 cubic feet of gas per B.H.P. hour.

Lützky.—The Nuremberg gas engine, designed on the Lützky system, is an interesting little motor, intended chiefly for small powers, and differing in several respects from the usual type. It is vertical, with the cylinder at the top, the piston working down through a connecting-rod upon the crank shaft, placed in a hollow conical base plate below. There are two flywheels, and the inventor asserts that the engine combines the stability of a horizontal, with the compactness of a vertical motor. The valve gear is reduced to a minimum, and there is neither counter shaft nor eccentric. Admission is by two automatic lift valves at the top of the cylinder. Through the first the gas passes into the mixing chamber, the second rises to admit the charge of gas and air into the cylinder, but the two are so connected by levers that the admission valve can fall, but cannot rise without raising the gas valve. The exhaust valve at the side of the cylinder is worked by levers and a cam on a small counter shaft, driven from the crank shaft by spur wheels, 2 to 1. The pressure of the gases prevents the gas admission valve from rising while the exhaust is open. The speed is regulated by a pendulum governor on the crank shaft, as in the Simplex engine. If the speed be normal, the lower heavier weight at the bottom of the pendulum is pushed outwards at every stroke by an eccentric on the shaft, and returning, releases the levers opening the exhaust from a notch on a disc, and the valve closes. But if the speed be too great, the pendulum weight does not strike against the eccentric in time, the levers remain fixed in the notch, the exhaust is held open, and the gas admission valve cannot rise.

A 6 H.P. Lützky engine was tested by Professor Schöttler in Germany. When running without the governor at a mean speed of 200 revolutions per minute, the consumption of gas was 24 cubic feet per hour per H.P. When the governor was put on, the engine made 180 revolutions per minute, and the consumption at half power was 28 cubic feet per hour per H.P. The gas used was exceptionally rich. Good drawings of this engine will be found in the *Zeitschrift des Vereines Deutscher Ingénieure*, August 22, 1891. It is made in sizes from 1 to 10 B.H.P., and runs at 180 revolutions per minute. The same engine is constructed by Köbers in Harburg.

Berliner Maschinen-Bau Motor (Kaselowsky's Patent).—The gas engine made by the Berliner Maschinen-Bau Gesellschaft, formerly Schwartzkopff, in sizes from 1 to 30 B.H.P., is of the four-cycle horizontal Otto type. and stands on a strong foundation.

Hot-tube ignition is used, there are no slide valves, and the lift valves for admission and exhaust are worked by a counter shaft, at right angles to, and driven from the main shaft. A conical pendulum governor regulates the quantity of gas automatically, according to the power required. The consumption is said to vary with the size of the engine from 23 to 35 cubic feet of gas per hour per I.H.P., and the average speed is from 220 to 160 revolutions per minute. For sizes above 20 H.P. two cylinders are generally used. The same engine, on Kaselowsky's patents, is also made for oil only in England by Messrs. Stephenson, of Newcastle-on-Tyne, and is known as the "Rocket" (p. 332).

Sombart.—The Sombart engine, formerly made by the firm of Buss, Sombart & Cie., and now by Fried. Krupp, Grusonwerk, Magdeburg, and first exhibited in 1886, is one of the older motors, the original vertical type, in which the charge is admitted and fired through a slide valve, being still retained for the smaller sizes. In some respects it resembles the Adam and Koerting, and the ordinary four-cycle is used. The admission and exhaust valves were formerly driven by spur wheels, 2 to 1, on the crank shaft; they are now worked by eccentrics from the valve shaft. Gas and air are admitted through a slide valve acted on by a rod from this eccentric; the exhaust is opened from it by means of a roller and levers. Ignition was obtained in the same way as in the Wittig and Hees engine (see p. 65), by the propagation of an external flame through a passage in the slide valve. The pressure was equalised, and the flame protected in a special manner, explained in the description of that engine. This arrangement has now been superseded by hot-tube ignition. The engine is controlled by an inertia governor, acting by the partial or total suppression of gas.

Much stress is laid by the makers upon the speed, in the construction and working of this engine. In common with others who have given attention to the subject, they maintain that it is more advantageous to run a gas engine at a comparatively low speed, and that the gain in power obtained by increasing the number of revolutions is counterbalanced by the wear and tear, and the greater consumption of gas and oil. Few of their engines are intended to be driven at more than 150 revolutions per minute. They no longer, however, make them exclusively vertical, although, owing to the large size of the piston and length of connecting-rod in proportion to the stroke, the vertical engines are said to run with great regularity. Two vertical and two horizontal Sombart engines were exhibited at Chicago. In the latest horizontal types ignition is by a lift instead of a slide valve, driven by a lever from the rod working the admission valve. In engines intended for driving dynamos the quantities both of gas and air are automatically varied by the governor in accordance with the load. As the

amount of air, as well as of gas, is regulated, the quality does not vary, whatever the speed, but the mixture is more diluted by the gases of combustion, and hence the charge burns more slowly if the normal speed is exceeded. The consumption of a 16 H.P. engine is given by the makers at about 22 cubic feet of gas per H.P. hour. The Sombart motor is made vertical in sizes from $\frac{2}{3}$ H.P. to 12 H.P., and runs at 200 to 160 revolutions per minute; horizontal with one cylinder from 3 to 75 H.P., and for two cylinders from 40 to 150 H.P., and a speed of 230 to 130 revolutions. Drawings of the earlier type will be found in Schöttler, of the later in Witz.

Capitaine.—Theory.—Among engines recently introduced, an interesting and original motor is the vertical Capitaine. The inventor, Herr Emil Capitaine, is opposed in opinion to MM. Buss and Sombart, as regards the relative values of high and low speeds. In a paper communicated to the *Verein deutscher Ingénieure* (vol. xxxiv. of the *Zeitschrift*), he maintains that the greater the number of revolutions, the better results will be obtained. At the same time he advances the novel point, that the piston speed may be quite different from, and independent of, the speed of expansion of the gases. Though usually classed together, the two are not synonymous, and their effect is by no means the same. If an engine be constructed, running at a certain speed, with a small diameter of cylinder and a long stroke, the speed of the piston will be considerable, and the speed of expansion relatively small. On the other hand, if another engine, going at the same speed, have a short stroke and a large diameter of cylinder, the piston speed will be relatively small, and the speed of expansion great. Combustion, however, can never be instantaneous, and therefore the speed of the piston should be limited to the rate of combustion of the charge. The Otto engine owes its success partly to the carefully designed ratio between combustion and the speed at which the gases expand. To every speed of revolution in a gas engine, a certain rate of combustion corresponds. Hitherto attempts to increase the efficiency have been made by—1, More or less rapid combustion; 2, Raising the temperature of the cylinder walls; 3, More perfect expansion of the gases; 4, More complete expulsion of the products of combustion; 5, Greater compression. All these improvements, combined with a suitable rate of combustion, have yielded good experimental results. Herr Capitaine is himself of opinion that, to obtain greater economy in a gas engine, expansion ought to be more rapid, and explosion practically instantaneous; the diameter of the cylinder should be increased, and the stroke shortened.

The disadvantages of running at high speed are—1, More rapid wear and tear; 2, Uncertain ignition; 3, Incomplete combustion; and 4, Vibration. Against these drawbacks Herr

Capitaine sets the gain of reduction in size and cost. If an engine can be made, without overheating, to run at twice as many revolutions per minute as another, its dimensions may be smaller, it will be lighter, less expensive, and the cost of transport less. Hitherto when engines have been tested at high speeds, no great gain in economy has been observed. Being constructed to run at a given number of revolutions per minute, and their ports proportioned to this speed, and to a given rate of combustion, they cannot be expected to work as efficiently, when they are driven at a much higher speed. The whole of the charge cannot reach the igniting chamber of the cylinder at the moment of explosion; part of it is ignited afterwards, and expands too late to act usefully on the piston. Herr Capitaine found, when testing an engine constructed to run at a high speed that, when making 320 revolutions per minute, an excellent indicator diagram was obtained. When the speed was increased to 800 revolutions, the efficiency was much lower, and diminished in proportion to the increase of speed. The number of revolutions should not be in excess either of the speed of propagation of the flame, or the development of pressure in the gas.*

Capitaine Engine.—In the Capitaine the piston speed is the same as in other motors, but the number of revolutions, or speed of expansion of the gases, is doubled. Another distinctive feature claimed for this engine is that, by an ingenious arrangement of the admission port, the incoming charge is kept apart from the products of combustion, and not allowed to mingle with them. The engine is of the single-acting vertical type; a sectional elevation is shown at Fig. 98. The disposition of the valves and working parts is similar to that of the Lützky engine. The cylinder A is at the top, and the piston P works down upon the crank shaft K, which, with the flywheel, is below. Gas and air are admitted from above through a double-seated automatic lift valve. The air enters at D and passes down into the wide port through the bottom of the valve at *c*, the gas through the upper seat of the valve at *f*. The top and bottom of the valve are connected by a spring, *s*, and work independently. Before passing through *c* into the cylinder, the gas and air mingle in the annular chamber formed by the valve, which imparts to them a circular motion of considerable velocity. They next impinge against a projection, *g*, and the wide diameter of the port checks their velocity, and forces them to enter the cylinder in a steady stream. This is the method also employed to prevent the fresh charge from mixing with the gases of combustion, which are discharged through the exhaust port at the side E.

* See on the subject of speed in Gas Engines the summary of Dr. Slaby's experiments, in Appendix.

The piston having drawn in the charge, the up compression stroke drives it into the hot ignition tube B. This tube is made

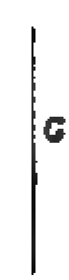


Fig. 98.—Capitaine Gas Engine—Sectional Elevation. 1888.

of porcelain, which is said to afford more resistance than any other substance to the heat and the high pressure, and is more easily kept at an equal temperature. In its passage through the admission port, a portion of the incoming charge is directed at once into the ignition chamber. As there is no timing valve the gases enter freely, and the mixture is supposed to ignite more readily, because part of it is already in contact with the hot ignition tube. The exhaust valve E is driven by a rod from an eccentric, H, on the crank shaft. Above the termination of this rod is a hollow lever, into which the projecting end of the exhaust spindle fits at every revolution. But it is only at every other revolution that a second lever is interposed between them, and the eccentric, pushing up both levers, reaches and opens the exhaust valve.

The ordinary four-cycle is used in this engine. The centrifugal governor G is on the crank shaft, and acts through a rod, *r*, and a catch on the lever opening the exhaust. If the speed be too great, the balls rise and draw the rod outwards. The knife edge of the lever misses the catch, the exhaust valve remains open, and no fresh charge can enter the cylinder, till the speed is again reduced within normal limits. All the wearing parts in this motor are carefully designed, wide and large. The inventor claims a considerable economy in the consumption of gas. In a trial on a 3·36 B.H.P. engine, with a cylinder diameter of 6·6 inches, and 6·4 inches stroke, and making 300 revolutions per minute, 27·4 cubic feet of town gas were used per B.H.P. per hour. The usual speed of the engine is 360 revolutions, and it is made both horizontal and vertical in sizes from 1 to 20 H.P., by the firms of Grob & Co., of Leipzig—Eutritsch, and Swiderski, also of Leipzig. The makers have introduced a circulating water tank, to supply the jacket of the cylinder, in which the water is kept cool by a small fan, &c. The engine has been often exhibited of late years, at Chicago, Erfurt, Antwerp, the Crystal Palace Electric Exhibition, &c., but it is now chiefly worked with petroleum (see Part II.).

Various.—The same may be said of the small engine by Januschek at Schweidnitz, Silesia. For lighting gas it is made in sizes from 1 to 7 H.P vertical, and 2 to 16 H.P. horizontal. The Schweizerische Maschinen Fabrik at Winterthur, Switzerland, construct the Kjelsberg engine, also made by Ludwig Nobel at St. Petersburg, and described in the oil engine section. The gas motor is vertical, in sizes from 1 to 6 H.P., and runs at 200 to 160 revolutions per minute. Both these types are chiefly intended to be used with oil, and are made in large numbers.

Another small gas engine, vertical and horizontal, has been brought out by Balduin Bechstein, of Altenburg. It is of the ordinary four-cyle type, and carries a slide valve for admitting the gas and air and igniting the charge, worked by wheels

2 to 1 and a rod from the crank shaft. The governor acts on the gas valve, the exhaust is driven from an auxiliary shaft. In other respects the engine resembles the Otto. It is made in sizes from ½ to 20 H.P., and runs at 160 to 180 revolutions per minute.

The engine made by Seck & Co., Oberursel, and known as the "Gnom," is chiefly intended to be driven with petroleum, and a description will be found in the oil engine section. As a gas motor, it is in sizes from 1 to 15 H.P., vertical only, and runs at 400 to 250 revolutions per minute.

MM. Martini, of Frauenfeld, Switzerland, make both oil and gas engines of the Otto type, with hot-tube ignition; the speed is regulated by the governor acting on the exhaust. For lighting gas they are in sizes from ½ to 10 H.P., and their speed is about 180 revolutions per minute.

Gas engines of the ordinary four-cycle Otto type are also made by **MM. Escher, Wyss & Cie.**, of Zurich, horizontal, in sizes from 2 to 50 H.P., vertical from 1 to 5 H.P., and run at 230 to 150 revolutions per minute.

CHAPTER XV.

GAS PRODUCTION FOR MOTIVE POWER.

CONTENTS.—Gaseous Fuel—Natural Gas—Coal Gas—Distillation—Combustion—Bischof's System for Generating Gas—Thomas and Laurent—Kirkham—Siemens—Pascal—Tessié du Motay—Strong—Lowe—Wilson — Dowson — Experiments — Tangye — Taylor — Thwaites — Various—Lencauchez.

THE first attempts to produce gas from coal were made as an experiment to obtain light, without any intention of utilising it as a motive force. The process of extraction was too costly for the gas to be employed to drive the motors invented at the beginning of the century, and many were the devices described by the patentees, to obtain a suitable explosive gas. In one of the earliest gas engines, brought out by Street in 1794, he proposed to generate a gas to act on a piston by sprinkling a few drops of petroleum or turpentine on the bottom of a cylinder kept at a red heat. The liquid was evaporated, exploded, and drove up the piston. Barber obtained gas for driving his engine by heating coal, wood, &c., in a retort, according to the method now practised in gas works. The process of making gas was in its infancy, carried out only in large towns and cities, and there was much prejudice against it. It was also very dear.

Practically in those days there was no gas to be had, and it was impossible to produce it cheaply, for driving small motors.

Gaseous Fuel.—As a fuel, however, coal gas was used long before its advantages as a motive force were perceived. During the first half of the century, as soon as the great value of steam was recognised, the economical use of coal became an important question. Without fuel, steam could not be generated, but although this is still usually done by burning coal under a boiler, it has long been known that it is rather wasteful. It is difficult by direct combustion to obtain temperatures as high as when gases previously extracted from the fuel are burnt. For chemical purposes, where great heat is required, gaseous fuel has been in use for many years. Cheap gas, made in producers or generators, is now extensively employed in the manufacture of iron and steel, and other metallurgical processes, as being better and cheaper than burning the coal itself. A fresh stimulus was given to its production as soon as gas engines began to attract public notice and favour. It was seen that the maximum economy in driving them could never be attained as long as they were worked with town gas, and inventors have for twenty years laboured to produce a cheaper and equally efficient gas.

There are many ways of extracting gas from fuel. The composition of different gases will be found in Chapter XVII., and it is only necessary here to mention, without going into details, the methods by which it is obtained. These consist in bringing together, with or without combustion, the chemical constituents of the coal and air, carbon, oxygen, hydrogen, and their compounds. If the hot fuel is moistened with water or steam, the quantity of hydrogen is increased; if air be introduced, a much greater amount of oxygen is added. In either case the carbon in the fuel unites with the oxygen of the air or of the water, and more carbonic oxide is produced than when the gas is formed from the chemical elements contained in the coal only. If the fuel is burnt in a closed vessel, and steam added and evaporated, the gas produced is richer in hydrogen than if air is admitted. When air is introduced, the same process takes place, but instead of hydrogen being liberated, there is a large residuum of inert and useless nitrogen.

Gaseous fuel may be divided into four classes, namely:—I. Natural gas. II. Oil gas, obtained from petroleum, vegetable oil and refuse, shale, fat, resin, &c. III. Carburetted air, or air saturated with volatile spirit. IV. Gas extracted from coal, wood, peat, and other varieties of fuel, either by distillation, or with the addition of air or water. In the latter case it is called power or water gas, or producer gas. We will now proceed to consider generally these four methods of gas making.

I. **Natural Gas.**—The process of generating gas from coal, or from the vegetable substance which forms the basis of coal, is

carried on by Nature as well as by man, though on an infinitely larger and slower scale. The gas is produced by the heat of the earth and the slow combustion of chemical decomposition. Gases exhaled from swamps and commonly known as "will o' the wisp" or marsh gas, are only a variety of lighting gas, which when artificially produced contains about 40 per cent. of marsh gas. As the decaying vegetation of swamps, bogs, and forests undergoes further decomposition or slow combustion, a fresh layer of soil is formed over it, and it passes very gradually during agès of time through the stages of peat, lignite, brown coal, and eventually to coal. Time, the earth's heat, decomposition and oxidation, and pressure, frequently cause the escape into the atmosphere of the gases thus generated. Of this the disastrous explosions in mines afford an example. Marsh gas or carbonic oxide (usually termed "fire damp" or "choke damp") distilled, so to speak, from coal, and at a high pressure, are liberated by excavation, and rush into the mine workings, often with fatal consequences. Where the gases find a natural outlet at the surface through fissures in the ground, as in many places in North America, and in Russia along the shores of the Caspian Sea, they are given off from the earth harmlessly. This natural gas, consisting almost entirely of marsh gas, is of excellent quality for lighting and heating purposes, and contains more heat than artificially made gas. Formerly it was allowed to escape to waste, but it is now partially utilised, and furnishes the greater part of the lighting gas used in several towns of the United States.

II. and III. The methods of producing gas from oil, and of charging air with petroleum spirit (carburetted air), will be described in the second part of this work.

IV. **Coal Gas.**—The gas used for lighting and heating is extracted from coal in two ways, either by—

1. Distillation, or the application of external heat to the coal.
2. Combustion, or actual ignition of the coal.

Distillation produces a much richer gas, and is the process universally used in gas works. The cheaper and inferior kinds of gas, such as water or producer gas, are obtained from combustion. These are employed as fuel instead of coal, and to drive gas engines. Professor Witz draws a further distinction between hot and cold distillation; the latter is chiefly employed for carburetted air.

1. **Distillation of Coal.**—The earliest method of obtaining gas from coal, first practised by Murdoch, was to heat the coal in closed retorts, and distil the gas from it. By this process the gases are given off, leaving a residuum of coke, &c. As the air is carefully excluded, the distilled products contain no gases except those already in the coal. Roughly speaking, two-thirds of the constituents are hydrogen, carbon, and their combina-

tions. It is only of late years, since gas motors have been made for larger powers, that the need of a cheap substitute for this distilled or town gas has been felt. As long as it was required only for illumination, the quantity used by each consumer was too small, to make economy of production a relatively important question. As far as the heating value of town gas is concerned, it is well suited for driving a motor, but it is unnecessarily pure for this purpose, and the price per 1,000 cubic feet is relatively great. To produce town gas separately for driving small motors is, of course, impracticable, on account of the cost of production, &c. For some time, therefore, much attention has been paid to the production of a cheaper gas, less pure, but not liable to deposit carbon in the passages and ports of a motor.

2. **Combustion of Coal.**—The second method of manufacturing gas is by burning the coal, and three processes are employed, each producing a different kind of gas. In all of them, ordinary atmospheric air is required to assist combustion.

In the first process a forced air blast is used. The gases are rapidly generated by driving a current of air through the glowing coal, and combustion is thus stimulated. This furnishes what is called producer gas, and sometimes Siemens' gas, because it was first introduced by Sir William Siemens, as a fuel and substitute for solid coal. This gas is often used for heating purposes, but is not rich enough to drive a gas motor.

The next kind is known as water gas. Here the method followed is also to burn the coal, and when it is in a state of incandescence, a jet of steam is injected into it. The steam is decomposed into oxygen and hydrogen, which recombine with the gases from the coal. The carbon present unites with the oxygen, and forms carbonic oxide and carbonic acid, and the greater part of the hydrogen is set free. A very rich gas is thus produced, which contains a larger percentage of the heat in the coal than gas made on any other system. Water gas is much used in America as fuel, instead of ordinary coal, because anthracite, from which it is made, is cheap and abundant. One disadvantage of this method is that the gas cannot be continuously produced. The blast of steam lowers the temperature of the coal, and after an interval of about ten minutes, there is not enough heat to cause decomposition and recombination of the chemical elements forming the gas. The process of injection is then stopped for a time, and air instead of steam introduced to revive combustion. As a rule, water gas and producer gas are made alternately in the same apparatus.

The third system is a combination of the two preceding methods. Instead of alternately injecting steam and air into the mass of incandescent fuel, both are admitted together. The jet of steam carries with it into the fuel a current of air duly proportioned, and the gas, though poorer in quality, can be made

continuously. There are now several applications of this system. It was first brought out and patented in England about 1878-79, by Mr. J. Emerson Dowson, and the value of his gas for driving motors is now fully recognised. About the year 1887, another method was introduced in France by M. Lencauchez, and is described further on. Engines driven with cheap gas give less power for the same cylinder dimensions as when worked with lighting gas, but the explosions and heat are not so great, and the wear and tear of the parts are rather less.

These three last kinds of gas, producer, water, and power gas, are usually made from anthracite or coke. If ordinary coal is used, the tar, ammonia, and other residual products are rather difficult to get rid of. Efforts are now, however, being made (1896) to utilise common coal, and sometimes fuel of all kinds. Some of the modern producers make gas from poor, and even from bituminous, coal. A distinguishing characteristic of these gases is that they contain a much larger quantity of carbonic oxide than lighting gas. Carbonic oxide is highly poisonous, but has no smell, and care is needed, in using it, to prevent any escape.

Bischof.—The earliest attempts to obtain gas for heating purposes from the combustion of coal, instead of from distillation, were made by Bischof in 1839. Peat fuel was burnt in a brick chamber, air at atmospheric pressure was admitted from below, through holes in the covering of the ashpit, and the gases generated during combustion were drawn off through a chimney and damper from the top of the furnace chamber. In 1840 Ebelmen made a furnace for generating gases, worked by a blast of air, and a much larger quantity of gas was produced by this means than in Bischof's apparatus.

Thomas and Laurent.—But the merit of being the first to design a practical gas producer belongs to MM. Thomas and Laurent, who, between 1838 and 1841, constructed a gas generating furnace, in which many modern improvements were anticipated. Air compressed by a blower was admitted at the bottom of a furnace, and the decomposition of the air was assisted by the injection of superheated steam, in the proportion by weight of 35 parts of air to 1 of steam. The height of the generator was sufficient to cause all the oxygen of the air to be transformed into carbonic oxide and carbonic acid. The fuel used was charcoal, wood, peat, coke, and anthracite.

Kirkham.—Another remarkable apparatus was brought out in 1852 by Messrs. Kirkham, who, working independently but on the same lines as Thomas and Laurent, produced their gas by the direct combustion of the fuel in a furnace, instead of by applying external heat to the coal, and distilling the gas from it. They were the first to use what is called the "intermittent" system of gas making—that is, the alternate admission of steam

and air to the coal. The fuel being kindled in the generator, a blast of air was turned into it, until combustion was thoroughly established; the air was then shut off, and steam was injected and quickly decomposed by the heat. After a short time the admission of steam was stopped, and air again introduced to revive combustion. Other gas producers were brought out by Ekmann in Sweden about 1845, Beaufumé in France in 1856, and Benson in 1869. In most of these early efforts, the object was not so much to generate lighting or heating gas from coal, as to utilise the waste gases from furnaces.

Siemens.—Several important gas producers were introduced with successive improvements by Sir W. Siemens, who gave his attention to the subject as early as 1861. His main object was to produce a gas which could be used as a substitute for ordinary fuel in furnaces, and he was the first to bring the question of gaseous fuel prominently forward. In his producer a very slow draught of air and slow rate of combustion are employed, and the gases are cooled as they leave the generator. His designs have since been perfected, and the Siemens' improved gas generator is now largely used for all sorts of metallurgical and manufacturing purposes. The two forms of gas producers introduced into France by Minary in 1868, and his later recent apparatus were invented with the same object, of replacing solid fuel in furnaces. A useful little generator was brought out by Dr. Kidd in 1875, intended to provide a cheap gas for domestic use and cooking. With the exception of the Siemens' apparatus these were all on a small scale, and none of them were originally intended to generate gas for working motors.

Pascal.—Pascal in 1861 was the first to develop the ideas of Thomas and Laurent, and those of Kirkham, and to test practically a system for manufacturing cheap gas, by the addition of steam and air to the incandescent fuel. Except in its application, his method differed little from theirs. A cylindrical gas generator filled with coal was surrounded by a boiler with which it communicated. The coal was fired, and steam from the boiler admitted alternately with air from a blower, worked by the motor. Pascal's system of making gas has long been discontinued.

Tessié du Motay.—Another method brought out by M. Tessié du Motay in 1871 is still used in America. A brick furnace, enclosed in a wrought-iron cylindrical shell, is charged with fuel from above, and the gas drawn off through an annular space at the top. Air is introduced through a blast pipe running across the centre of the furnace, and the ashes and clinker are discharged below. This is said to be one of the best of the intermittent gas producers, and is simple and efficient. At the Municipal Gas Works, New York, it is used at three stations, and 16 million cubic feet of gas produced per twenty-four hours.

Power Gas.—These different generators exhibit the successive steps in the production of gas from coal. The first improvement on the process of distillation was the substitution of internal for external combustion. Instead of the outward application of heat, the fuel was burnt in the furnace, and the gas led off from it in pipes. A blast of air was next introduced, to accelerate the production of gas; the last and perhaps the most important innovation was the addition of a jet of steam. The great cost of working the Lenoir engine gave a fresh stimulus to the production of cheap gas. About 1862 two systems were proposed on the Continent for making water and generator gas. In the first, designed by M. Trébouillet, retorts filled with charcoal were brought to a red heat, and superheated steam forced through them. Charcoal was also used in the other method, invented by M. Arbos of Barcelona. The generator was in two divisions. The upper part contained water, and formed a kind of boiler and superheater. The steam mixed with air was admitted at the bottom of the furnace.

Strong.—Two systems, the Strong and the Lowe, for making cheap gas by admitting steam and air intermittently into burning fuel, were introduced about 1874. Both are of American origin,

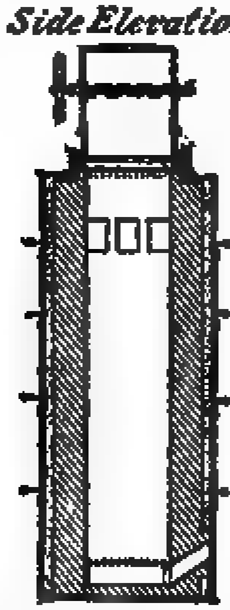


Fig. 99.—Strong Gas Producer. 1874.

and are now often used, especially in America. Fig. 99 gives a view of the Strong apparatus, and shows the method of generating and purifying the gas, and superheating the steam before it enters the furnace. A is the generator filled with anthracite or coke, charged through the hopper H above, or through the doors, *p*, *p*. I and J are the heating chambers, loosely stacked with fire bricks. A forced blast of air enters at B below the furnace, and another current is admitted at C. As soon as the coal is kindled in A the air blast from B causes active

combustion, and the gases generated are driven into the first chamber I. Meeting here the draught of air from C they are forced down through the fire bricks, and up in the direction of the arrows through the second chamber J till they reach the reservoir R. As soon as the fuel in the furnace A, and the bricks in the chambers I and J are at a red heat, the air is shut off from the blast pipe B, and the opening C, and steam introduced at G passes through the chambers and the furnace in the reverse direction to the air. In its passage through the red-hot fire brick it becomes superheated. At the top of the furnace finely-powdered fuel is sprinkled into the steam. Brought in contact with this coal dust continuously fed from the hopper by means of a slow moving Archimedean screw, the steam instantly separates into its elements, and these combine with the carbon to form rich water gas, which is drawn off at D. After a few minutes combustion slackens, and the process is reversed. The steam is shut off, the forced blast of air again admitted, and producer gas given off. The Strong gas is specially adapted for heating. It is perhaps the best of the producers working on the intermittent system, and generating gas alternately from air and from steam.

Lowe.—The Lowe process resembles the Strong in several respects, and contains a generator and a single superheating chamber; in the latter the gases given off during combustion are heated, instead of the steam. The producer is worked intermittently. By the side of the iron cased brick generator furnace is a superheating chamber filled with loose bricks, a reservoir of water, and a scrubber for purifying the gases. The generator being charged with anthracite, combustion is started by a blast of air. The hot gases given off rise to the top of the generator, and are conveyed through a pipe to the lower part of the superheater, where a fresh current of air is admitted, kindling the gases, and causing the flames to rise through the loosely stacked bricks. As soon as the bricks and the coals in the generator are at a red heat, the air is shut off, and superheated steam blown into the furnace. A small stream of petroleum drops from above on to the glowing fuel, and as the gases produced by the decomposition of the steam pass upwards through the generator, the volatilised oil mixes with them and forms hydrocarbons. The gases next pass through the superheating chamber, which being always maintained at a constant heat, the composition of the gases is always uniform. They are then purified by passing through the water tank, and the scrubbing chamber filled with wet coke. The gas produced by the Lowe system differs in some respects from others, and the inventor asserts that the quality does not vary.

Wilson. — The Wilson gas producer, like those already described, was not originally intended to generate gas for

driving a motor, but if the furnace be fired with anthracite or coke, and the gases well washed, they can be used for that purpose. The method of introducing the steam is novel. It enters under pressure through a narrow tapering nozzle, and carries with it a strong current of air in the proportion of 20 parts of air by weight to 1 of steam. In order that the whole of the air and steam may perfectly combine with the fuel, they are delivered into the centre of the glowing coal. Before

Fig. 100.—Dowson Gas Producer—Boiler and Holder. 1895.

they are carried off, the hot gases from the furnace are led into a chamber round the upper part of the producer, where the coal is fed in from a hopper. The fresh fuel is heated before combustion by these gases, and the chamber acts almost in the same way as a retort. The producer has also an automatic arrangement for carrying off the ashes and clinker.

Dowson.—It is to Mr. J. Emerson Dowson that the merit belongs of having fairly inaugurated the process by which steam

and air are admitted to a furnace together, to furnish power gas for driving engines. The gas obtained is poorer than water, but richer than producer gas; it can be rapidly and continuously generated, and with the proper admixture of air is well adapted for driving gas engines. It possesses the further advantage of being much cheaper than lighting gas. Before its introduction, it was considered impossible to work gas engines as economically as steam engines of about the same power. With few exceptions only small motors were made, and owing to the expense of town gas, it was supposed that large power gas engines could never compete successfully with steam. The adoption of Dowson gas has shown that it is possible to work a 100 H.P. gas engine with much greater economy than a good 100 H.P. steam engine, and a still more economical consumption of fuel has been obtained with an engine indicating 170 H.P. From this point of view, the services rendered by Mr. Dowson, in making it possible to produce power more cheaply by the use of his gas, are very great. It is now employed in a large number of motors, and although the cost of driving them has already been much reduced, the inventor is of opinion that "still better results can and will be obtained when an engine is designed to give the best effect with this gas."

Fig. 100 shows an external view of a complete Dowson gas plant up to about 100 I.H.P. To start production, nothing is required except anthracite or coke to fill the generator, and water to evaporate into steam for injection into the fuel. The steam pressure varies from 30 to 50 lbs. per square inch, according to the size of the gas plant to be served. The wrought-iron generator is seen in the front (to the left), and the small vertical boiler for producing the steam stands beside it to the right. The boiler has a closed grate, and tubes in the uptake, in which the steam is superheated, before it passes to the lower part of the generator. Between the boiler and generator is an injector, through which a current of air is forced, by the velocity of the steam. The cylindrical generator is lined with fire brick, and the fuel is fed in through the hopper above. The gases generated by the combustion of the anthracite or coke combine with the oxygen derived from the decomposition of the steam and air, and are conveyed through a cooler and pipe into the hydraulic box, which is partly filled with water. The gases passing through the water are washed, and another pipe conveys them to the scrubbers, sometimes placed inside the gasholder, to economise space. One is filled with coke, continually moistened by water sprays; the gases pass from here into the second scrubber filled with sawdust, and thence to the gasholder.

To regulate automatically the production of gas, the following method is adopted:—The top of the holder is connected to a chain attached to the air injector. If too much gas is generated,

the holder rises, lifts this chain, and raises a valve from which the air and steam are allowed to escape, instead of entering the generator. As soon as production is reduced, the holder sinks, and the valve is released. At Fig. 101 is shown a Dowson gas plant at the flour mills of Messrs. Mead & Sons, Chelsea. The arrangement differs slightly from that already described, because the plant is larger, and the scrubbers are outside the gasholder, but the system is the same; the different parts are indicated by letters. The trial made with this producer is mentioned at the end of the chapter.

A large number of experiments have been undertaken with Dowson gas, and have proved its economy, and the relatively small cost of using it to drive engines. To make a proper comparison between a steam-engine plant and a Dowson gas plant and motor, the cost of the fuel should in both cases be given, and the generator considered as forming part of the gas engine, in the same way as a boiler forms part of a steam plant. In England the gas can be produced at a cost of about 2d. to 3d. per 1,000 cubic feet, according to the quantity required, but in the case of large works, where a steam boiler already exists, the consumption of fuel can be reduced, by utilising this steam for the generator. It should, however, be remembered that the gas contains about 55 per cent. of nitrogen and carbonic acid, as against about 8 per cent. of nitrogen in gas manufactured by the Strong process, but besides being continuously generated, Dowson gas has a higher calorific value than producer gas. It is about four times less rich in heating value than town gas, and requires less air for its combustion in the cylinder of a gas engine. The actual charge admitted is no larger than when town gas is used, because the ratio of air is much smaller. Instead of from 5 to 14 parts of air to 1 of gas, Dowson gas needs only from 1 to 1½. The exact proportion of heating value of average coal gas, as compared with Dowson, is 3·8 to 1.

Dowson gas can only be made with coke or anthracite, but both are easily obtained in England. It is yearly becoming more widely known and generally used. It is easily produced; the plant is compact and simple, occupies a small space, and requires little attention; it does not burn with a smoky flame, and deposits no impurities in the ports and valves of an engine. It can be made continuously, rapidly, and at a much lower cost than town gas. Most of the important firms now make engines for larger powers, to be driven by Dowson or other producer gas. An account of these will be found under the head of the different engines.

Besides its use for motive power, Mr. Dowson has lately adapted his gas for various heating purposes. In almost all cases where light is not required it may be substituted for coal gas, and can be used for furnaces, annealing ovens, chemical

Fig. 101.—Dowson Gas Plant at Mead's Flour Mills, Chelsea.

work, japanning, soldering, &c., and in many other manufactures.

Experiments.—Trials with Dowson gas will be found in the table. The Simplex engine was twice carefully experimented on by Professor Witz with Dowson gas. On the first occasion the engine indicated 8·10 H.P., and the consumption of gas per B.H.P. per hour was 86·8 cubic feet. In 1890 M. Witz tested the 100 H.P. Simplex engine, shown at the Paris Exhibition, and found the consumption 1·34 lb. English anthracite per B.H.P. per hour. Experiments made by MM. Teichmann and Böcking in 1887 on a 30 H.P. nominal Otto engine gave a consumption of 103 cubic feet of gas per I.H.P., equivalent to 1·67 lb. of fuel per B.H.P. per hour. Dowson gas is now used to drive all the engines at Messrs. Crossley's works, and it furnishes a total of from 250 to 300 H.P. A good test of economy is found in the average working expenses throughout the year of large engines driven with this gas. At Messrs. Spicer & Co.'s Paper Mills at Godalming the total I.H.P. is 600 to 700. In all the engines Dowson gas is used, and the average consumption during 20 weeks, including waste, was 1 lb. fuel—viz., anthracite for the generator and coke for the boiler—per I.H.P. per hour. The same results per I.H.P. have been obtained at the Crossley works during 35 weeks, with all their engines. In MM. Koerting's extensive engineering works near Hanover there are several engines driven by Dowson gas, with a total of about 300 H.P. At the Severn Tweed Co.'s Mills at Newtown, two trials, each extending over six days, were made upon four Crossley engines, driven with Dowson gas, and indicating a total of about 280 H.P. In the first trial anthracite was used, and the total consumption was 1·23 lb. per B.H.P. per hour. During the second the generator was fired with coke, and 1·73 lb. per B.H.P. per hour was used.

Two careful and important tests were made to test the economy obtained with Dowson gas. The first, by Tomlinson, was on a 15 nominal H.P. Atkinson Cycle engine, used to pump water from a well at the Uxbridge Waterworks. The well was 100 feet deep, and the water had to be pumped into a reservoir a mile and a half away. The engine was coupled direct to double-acting pumps 80 feet below the surface, and was driven at 86 revolutions per minute. The total quantity of fuel used was 1·06 lb. per I.H.P. per hour, or 1·48 lb. per water horse-power per hour; and about 16·4 per cent. of the heat units in the fuel were converted into total work, or 12 per cent. into water pumped. The other trial was made in 1892, on a 60 H.P. nominal Crossley-Otto engine, using Dowson gas. The trial was conducted by Mr. Dowson himself, and gave results more economical than any obtained with smaller engines. It is of special interest because it was made on the largest engine then driven with Dowson gas.

The maximum I.H.P. was 173·6, B.H.P. 147·6, but the engine did not run at full power, and the mean I.H.P. developed was 118·7. The fuel consumed during the trial was 0·76 lb. per I.H.P. per hour, including anthracite for the generator and coke for the boiler, but allowance was made for getting up steam. This trial was at Messrs. Mead & Co.'s Flour Mills, Chelsea.

An interesting series of experiments was made in 1895 on two 50 H.P. Crossley-Otto engines, driven with Dowson gas, providing electricity for the Mountain Railway at Zurich. Each engine had a gas generator attached, and one engine and gener-

Fig. 102.—Tangye Gas Producer. 1895.

ator were used to drive the dynamos, the other as a reserve. The ignition tube was heated by a flame fed with Dowson gas, and one boiler furnished the steam to both generators, if required. Each generator produced 10,593 cubic feet of gas per hour, or sufficient to develop 120 H.P. Two experiments were made to determine the efficiency of the engines under normal working conditions, and a third for the maximum power. The mean

heating value of the gas, taken constantly with a Junker calorimeter, was 162 B.T.U. per cubic foot, but it was found to vary greatly from hour to hour, depending more or less upon the quantity of coal, time of stoking, and power required. The total consumption of Belgian anthracite for the generator and boiler was 1·4 lb. per B.H.P. per hour; the mechanical efficiency at maximum power about 90 per cent. The diameter of the cylinders was 16·9 inches, and stroke 24 inches; number of revolutions, 160. Full details of this excellent trial will be found in the *Zeitschrift des Vereines deutscher Ingénieure*, Dec. 21 and 28, 1895.

Tangye.—Like most of the modern generators, this gas producer is practically automatic in action. The two improvements claimed for it are the effective feeding of the fuel into the generator without allowing the height of the fire, and hence the quality of the gas, to vary, and the careful treatment of the gas after it leaves the furnace. If steam is not available, a small separate boiler is required, and both the steam and air are superheated before entering the furnace, thus ensuring their rapid decomposition into gas. Fig. 102 gives a view of this gas plant. H is the conical-shaped hopper, with valve above, which holds enough fuel for several hours, and as the coal sinks gradually and automatically into the generator, the level is maintained uniform, and there is no disturbance of the furnace. The generator is lined with fire brick, L. The gases are led off through a wide pipe, K, with two passages, through the lower of which they pass to the box B where they are freed from dust. In this passage is a U-shaped tube, round which the gases circulate, and not only heat it, but also the upper passage N. The steam from the boiler is first drawn into this U-tube, where it is superheated, and thence to the blower box Q and mixed with air in the proper proportions for combustion. The two pass along the pipe N and the annular passage V in the lining of the generator to the hearth at E. Thus the steam is twice heated, first in the U-tube by the gases, and next in the pipe V by the furnace. The gases are led off down the centre of the cooler D to the dust box B, and thence to the hydraulic box G. Passing upwards at M through loosely stacked coke, moistened by water continually playing on it from above, they are finally carried down the centre and dried, and thence to the engine or gasholder. Although quite a recent invention, several of these plants are at work for driving engines, and making gas for heating and other purposes. The gas produced has a heating value of 160 B.T.U. per cubic foot, and the plant is said to generate 168,000 cubic feet per ton of Welsh anthracite. It can only be worked with anthracite or coke.

Taylor.—The special feature of this generator, made by MM. Fichet and Heurtey in France for driving the Niel engine, is

that the heat of the gases is refunded to the furnace, instead of being wasted by cooling them in the scrubber. The temperature of the furnace is thus raised, more water can be injected, and a larger quantity of richer water gas made than is usual with producer gas. The generator consists of a vertical fire-brick cylinder, slightly conical below, with an outer casing of sand; the grate is replaced by a revolving plate, worked by wheels from a shaft and crank handle. The combustible is fed in from above through a hopper in the usual way, and the height of the fire regulated by the nature of the fuel. The steam is generated in a small tubular boiler, placed in the upper part of a vertical column, down which the gases are led after leaving the furnace. Being drawn through an open injector, the pressure of the steam is sufficient to carry with it a proper quantity of air, and both pass upward through the column, in a contrary direction to the gases. They are thence conveyed through a pipe in the lining of the cylindrical furnace to the bottom of the hearth, and introduced into the centre of the fire, where the heat of the furnace decomposes them. The gases are carried off at the top, and after heating the boiler, and the fresh air and steam in the vertical column, pass through a washer, a column of wet coke, and then through a purifier to the gasholder. The quality of the gas, and the proportions of steam and air can be regulated by means of the steam jet.

Like other generators used in France, the Taylor gazogene can be fired with common French coal, and cheap non-coking coal of any kind. A trial of a Schleicher-Schumm Otto engine driven by Taylor gas (made by Winand in America) will be found in the table; the consumption of anthracite was 1·3 lb. per B.H.P. hour. This generator is much used in America.

Thwaites.—Another gas-making plant has recently been introduced by Mr. Thwaites, specially intended for the production of gas, not only from anthracite and coke, but from bituminous coal, slack, breeze, sawdust, peat, &c. Refuse oil (astatki) can it is said be converted into gas in this producer, either alone, or in conjunction with solid fuel. The system adopted, specially for bituminous coal, is a twin generator plant. Each cylindrical generator has its own hopper, feeding the fuel automatically into the producer, and in each the grate rests in a water bath, through which a blast of air from a fan is blown into the furnace, charged with steam from the evaporation of the bath, in its passage. The steam and air pass upwards through one furnace, and downwards through the glowing fuel of the second. The process is reversed about once a minute by an automatic arrangement closing or opening the corresponding valves. The gas being thus twice exposed to the heat of the furnace is so much purified, that it is said to require only one scrubber, through which it passes before it is led off to the holder,

or direct to the engine. When the gas from this twin producer is used for motive power, the inventor claims to have reduced the consumption to 1½ lbs. of common slack per I.H.P. hour, and good results have, it is said, been obtained with gas made from Belgian peat. The incombustible residuum, as ammonia, tar, pitch, &c., can also be profitably employed, the heat from the exhaust gases may be utilised to heat the air passing to the generator, and as the fan for the force blast is usually driven from the motor, a working cycle, more or less complete, is said to be the result. Drawings of this plant, which appears to be still in the experimental stage, will be found in the *Engineer*, July 5, 1895, with a description of a generator erected in the north of London, for driving a gas plant to produce electric light. No trials have yet been published.

Various.—The **Kitson** is another gas generator on the same principle as the Tangye, in which the heat for evaporating the water into steam is furnished by the generator itself. Although this producer has been used to drive a Koerting and an Atkinson engine, it does not appear to be made at present; the parts are rather complicated.

Other processes for making poor gas are the Longsden, the Loomis, and the Guyon and Métais, but none of these, to the author's knowledge, have been used for driving engines. The Bénier gas producer is described at p. 162.

Lencauchez.—This system for making gas is much used in France; the English patent (No. 4798) was taken out in 1891. It was invented by M. Lencauchez, and the apparatus being first made at the Chantiers de la Buire, Lyons, it was originally called the Buire-Lencauchez system. In outward appearance the generator differs little from the Lowe, but the gas is continuously produced. It has now been adopted by MM. Delamare-Deboutteville and Malandin, the makers of the Simplex engine, and they have added a Lencauchez gas producer to many of their motors, from 16 to 100 H.P.

Fig. 103 shows a sectional elevation, and Fig. 104 an external view of the apparatus, attached to a Simplex engine. A is the furnace or generator, with firebrick lining K, between which and the outer iron casing is a layer of sand, L. C is the grate, B the scrubber filled with coke, from whence the purified gases pass through Y to the gasholder. The fuel is charged through a hopper, M N, above the furnace; the ashes are withdrawn once in twenty-four hours through the door F. A current of air, previously heated by the furnace, enters the generator at H from a fan or blower worked by the engine, and is driven into the closed pan G. By a cock at W a small stream of water, preferably drawn from the jacket of the gas engine, is admitted into a hollow trough, E, and falling through the bars D D on to the grate is there evaporated, and mixes with the blast of com-

Fig. 103.—Lencauchez Gas Producer—Sectional Elevation. 1890.

pressed air. The two pass together into the furnace, and the surplus water is carried off at J. The gases are then led from the top of the furnace by the pipe S into the scrubber or purifier B filled with coke, upon which water from the siphon Z is continually playing through a perforated cone or distributor. V V are the grate bars, X the door for withdrawing and changing the coke. On their way to the scrubber the gases pass the hydraulic joint T, which is intended to prevent the return of any gas to the furnace. The water dripping through the coke is carried off at U. The gases are next delivered sometimes to a distributing chamber, sometimes direct to the gasholder. By an ingenious arrangement the furnace can be shut off for a few minutes, the injection of air and steam suspended, and the engine driven by gas from the holder while the grate is cleaned, an

Fig. 104.—Lencauchez Gas Producer and Simplex Engine. 1894.

operation only necessary once in twenty-four hours. The holder contains sufficient gas for starting the engine. The production of gas is regulated by a Valve I (through which the compressed air passes to the furnace), and which is attached by a chain to the top of the gasholder. As soon as the holder is filled, the valve I is automatically raised, and the air is not allowed to enter the furnace until the contents of the holder have been reduced.

Advantages—Consumption.—The special advantages of the Lencauchez gas producer are its economy of heat and its simplicity, no boiler being required. Both the air and water are usually heated before they enter the furnace, and heat is thus utilised. This producer can also be used to generate gas from cheap and poor coal. MM. Delamare and Malandin no longer find it necessary to burn English anthracite in their Lencauchez generators, but inferior non-caking French coal, which is much

cheaper. Hence the system is specially adapted for use where best coal is difficult to procure. French anthracite has neither the same calorific value, nor is it as pure as English. Gas made on the Lencauchez system with English anthracite has a heating value of 174 B.T.U. per cubic foot at ordinary temperature and pressure; when cheap French anthracite coal is used, its heating value is 152 B.T.U. per cubic foot. With large motors driven by Lencauchez gas the consumption of fuel is about 1·3 lb. of good anthracite per H.P. per hour. A 50 H.P. Simplex engine has been working continuously with this gas since 1888 at M. Barataud's Mills at Marseilles. It is said to require a consumption of only 1·2 lb. English anthracite per B.H.P. per hour. A description of other Simplex engines worked with this gas will be found in Chapter XI. The heat efficiency of this generator is from 75 to 80 per cent. of the total heat in the fuel.

In a paper published in the *Procès Verbaux de la Société des Ingénieurs Civils*, October, 1891, details are given by M. Lencauchez of the economy which can be realised by using large gas engines driven by cheap gas, made in special generators. A good gas plant, burning the commonest fuel, transforms more than 80 per cent. of the solid combustible into gas, while the best steam boilers, according to M. Lencauchez, seldom utilise more than 70 to 75 per cent. of the heat contained in the coal. The thermal efficiency of the gas engine being usually reckoned at double that of the steam engine, a total economy of about 50 per cent. of fuel may, the writer considers, be obtained by using poor gas instead of steam for motive power.

CHAPTER XVI.

THE THEORY OF THE GAS ENGINE.

CONTENTS.—Laws of Gases—Boyle's Law—Gay-Lussac's Law—Joule's Law of the Mechanical Equivalent of Heat—Thermal Units—Specific Heat—Carnot's Law—Perfect Cycle—Isothermal and Adiabatic Curves—Ideal Efficiency—Other Cycles—Indicator Diagrams—Entropy and Entropy Diagrams.

Laws of Gases.—No complete study of the gas engine is possible, unless it includes a knowledge, however slight, of the gas

14

itself, or working fluid, the physical and chemical laws governing it, and the chief phenomena taking place in the cylinder of an engine. None of these phenomena are the result of chance. The laws controlling the action of gases have been accurately determined. The force of the explosion of gas in a cylinder seems, at first sight, impossible to regulate. But it can now be defined with precision, and is always exactly proportioned to the pressure and temperature of the gas when admitted, and the amount of its dilution with air. Thus, if a certain weight of gas, composed of known chemical elements in a definite combination, and diluted with a given proportion of air, be admitted into a cylinder of known dimensions, its action can be accurately foretold, and the work estimated which it is able to do.

The term "working fluid" is applied to the medium of heat in thermal motors. It is equally correct to call it the "working agent," and the latter expression will here be used. No absolutely perfect gas is at present known, that is, a gas which obeys perfectly the theoretical laws, and cannot be condensed into a liquid by any change of temperature. But in the case of coal gas, air, or oil, the chief agents for the transmission of heat in internal combustion engines, the variation from a perfect gas is so slight that, for practical purposes, it may be neglected.

Of the different laws regulating the action of gases, two only are essential, in order to understand the phenomena in a heat engine. The first is known as Boyle's Law in England, and Mariotte's Law on the Continent. It was first propounded by Robert Boyle in 1662, and is as follows:—

Boyle's Law.—I. If the temperature of a gas be kept constant, its pressure or elastic force will vary inversely as the volume it occupies.

This proposition defines the relation between the three attributes invariably found in all gases, whatever their composition —temperature, volume, and pressure. The word temperature denotes the condition of a body as regards sensible heat; volume is expressed in cubic feet, and the specific volume of a gas is the number of cubic feet it occupies per lb.; pressure is the elastic force the gas exerts upon the walls surrounding it, reckoned in lbs. per square inch. All the phenomena taking place in a heat engine are produced by varying one or other, or all three of these attributes,—that is, by increasing or diminishing the temperature, the volume, or the pressure of a gas. Boyle's law may be illustrated by imagining a cylinder containing a piston, both perfectly tight. The piston is set half-way through the length of the cylinder, and gas admitted on one side of it; and the temperature of the gas being kept constant, the supply is next cut off. If the piston be then moved to its farthest limit, it will uncover the other half of the cylinder, and the available volume will be doubled. The gas will instantly ex-

pand, following the piston, and as no more is admitted, the same quantity will occupy twice as much space as before. But this increase in volume of gas will also be accompanied by a corresponding diminution in pressure. The force exerted by the gas on the piston will, at the end of the stroke, be half as much as before. If the space originally occupied by the gas be called one volume, and its pressure be taken as equal to that of the atmosphere, or in round numbers, a pressure of 15 lbs. on every square inch of the piston surface, the gas, when the piston has moved to the end of the cylinder, will occupy two volumes, but will exert a pressure of only $7\frac{1}{2}$ lbs. per square inch upon the piston. The temperature being always the same, the products of the pressure and the volume will remain constant. To express Boyle's law differently—

$$\text{Volume} \times \text{pressure} = \text{constant.}$$

Now let us suppose that the temperature be at the same time varied; quite different conditions are immediately introduced, and the law no longer applies. If heat be furnished to the cylinder described, and the temperature of the gas raised, without allowing the piston to move out, the gas will continue to occupy the same space as before, but the increase of temperature will cause the pressure to increase. The heat will force the particles of gas further apart, and the pressure or tension will rise until, if the temperature be continually increased without an increase in the volume, the gas will burst the cylinder. This expansion of gas through the application of heat, and its corresponding contraction when heat is withdrawn, has been carefully verified, and the degree of variation in volume or pressure, determined by experiment, has been found to be in exact proportion to the quantity of heat added to, or abstracted from, the gas. It forms the basis of the following second law of gases, called Charles' law in England, and the law of Gay-Lussac on the Continent.

Gay-Lussac's Law.—II. The pressure or the volume of a gas being maintained constant, all gases expand $\frac{1}{273}$ part of their volume, or increase in pressure $\frac{1}{273}$ part for every rise of 1° C. in their temperature. The law may be stated differently thus:—

Suppose a gas is at constant volume in a closed vessel, and exerting a pressure of 273 lbs. per square inch. For each degree Centigrade added to its temperature, the pressure of the gas will increase 1 lb. per square inch. If, therefore, its temperature be raised 10° the pressure will be 283 lbs. per square inch. The converse of the law also holds good. All gases contract in volume, or lose $\frac{1}{273}$ part of their elastic force, for each degree Centigrade by which their temperature is lowered. Therefore, if a gas at 0° C. be reduced 1°, it will contract by $\frac{1}{273}$ part of its volume, and if it were possible to continue the process, and to lower

gradually the temperature of the gas 273° C., a point would be reached, called the "absolute zero," at which the gas would possess neither volume nor pressure. This limit of the "absolute zero" is not a theoretical point, but definitely fixed by natural laws, and it is difficult to pass beyond it. According to the law of Gay-Lussac, more heat could not be abstracted, even if the lowest limit of temperature were not reached, because the gas would have no further power of contraction, and therefore of diminution in pressure.

No one has yet been able to reduce a body to this extreme of cold, although in recent experiments it has been approached. The "absolute zero"—viz., 273° below 0° C. and 461° below 0° F.—is, however, the basis of all calculations of temperature in scientific work. The zeros fixed by Fahrenheit, Réaumur, and Celsius are all arbitrary determinations, below which temperatures continually fall, but they cannot be used as the original starting point for measuring heat.* In calculating the heat in an engine, the temperatures are usually measured from the absolute zero, or ordinary temperature Centigrade + 273°. Now in the first law of gases there are only two characteristics of a gas and their variations to be considered. In the second law, a third is added, and the relation between the three is expressed thus:—

$$\frac{v \times p}{T} = \text{Ratio or R.}$$

Put into words this formula runs:—The volume v multiplied by the pressure p of any gas, and divided by the absolute temperature T, are equal to a certain fixed ratio, R. The same law may, of course, be expressed thus:—

$$v \times p = R \times T.$$

The value of R for air is 29·64.

This expansion of a gas $\frac{1}{273}$ of its volume for every degree Centigrade added to its temperature, is equal to the fraction 0·00367, called the coefficient of expansion. The term "coefficient" signifies a fixed quantity or mean value, accurately determined by experiment, and applying equally to all bodies possessing the same properties, and under the same conditions. If the amount of heat added to any gas be known, the degree to which it will expand can be exactly calculated by this coefficient. As it increases in pressure or expands in regular proportion to the heat added, it is evident that there must exist some fixed relation between the expansion of the gas, and the tem-

* The centigrade scale fixed by Celsius has been practically adopted in Europe and America for scientific work. It is often used in this book, in order not to confuse the student passing on to other and more elaborate theoretical works, in which he will find no other scale of temperature given.

perature producing it. This relation forms a link between the laws of gases we have just been considering, and those governing the action of heat, and furnishes a good example of the first and most important Law of Thermodynamics, the Mechanical Equivalent of Heat. It may be briefly stated thus :—

Joule's Law—Mechanical Equivalent.—I. Whenever heat is imparted to, or withdrawn from a body, energy is generated in proportion, or an equivalent amount of mechanical work is done by the body, or upon it by external agency. The proportion between the heat absorbed, or given out, and the work performed is always the same.

This law, which has given a new direction to scientific thought during the last half century, was fore-shadowed by Count Rumford and Sir Humphry Davy, and discovered almost simultaneously in England by Joule, in Germany by Mayer, and in France by Hirn. The priority is usually ascribed to Joule, who published the results of his experiments in 1843, and the law is known in England as the Law of the Mechanical Equivalent of heat, or briefly as Joule's Equivalent. It is twofold in its operation and effects, and may be expressed as :— heat is a form of energy, or Mechanical energy (work) may be converted into heat according to a definite law.

To explain it we will again use our illustration of a cylinder with an air-tight piston, containing a given volume of gas. As long as the temperature of the gas does not vary, its volume and pressure have been proved to stand to each other in exactly inverse ratios. As the one increases, the other decreases. If heat be added, the gas expands, the pressure rising in exact proportion to the increase in heat. It is the law of the mechanical equivalent which explains the reason of this increase in expansive power. Heat has been put into the gas, and disappears as heat, to reappear in some other form. Nor can it be otherwise. The Law of the mechanical equivalent is a necessary deduction from the principle that nothing in nature can be lost or wasted. All the heat imparted to the gas must be found again, either as heat, or transformed into some other form of energy. In the case of our cylinder and piston, all the heat will be changed into work, and will be absorbed in producing the expansive force of the gases driving out the piston. Were there no piston, and the cylinder open at one end, work, since it must be done by the expansion of the gases, would be done on the atmosphere. In no case can the heat imparted to the gas be lost. Either it is represented by the expansion of the gas, or carried off by radiation to the conducting substances surrounding the cylinder.

The earliest and simplest example of heat transformed into mechanical energy is shown by a cannon, which is really a primitive form of heat engine. The bore of the cannon repre-

sents a cylinder, the bullet is acted upon in the same way as a piston. A solid combustible is used to produce inflammable gas, but the effect is the same as in a gas motor. Heat applied to this combustible or powder causes it to explode, and the force of the explosion, or expansion of the gases generated, drives out the bullet with great velocity. Not only can heat be thus transformed into actual work, but the converse proposition that energy may be translated into heat, has been demonstrated by many careful experiments. Both are mutually convertible forces, and this may be verified by suddenly arresting the progress of the bullet. The energy of motion imparted to it by the heat of combustion and not yet expended, is immediately retransformed into heat, and the bullet is found to be much hotter than if it had been allowed to continue its course till its velocity was spent. Sir Humphry Davy demonstrated the truth of this proposition in another way, by his celebrated experiment of rubbing two pieces of ice together in a vacuum, without change of temperature. Water was produced, showing that the ice was partially melted, and the heat required to effect this change of state could only have been obtained by friction,—that is, by mechanical energy or work, as no heat had been added externally to the ice.

The theory of the Mechanical Equivalent is equally applicable, whether a gas be heated or cooled. If heat be imparted to it, and the gas allowed to expand, the particles are driven further apart; if heat be abstracted they shrink. Work will be done *on* the gas by contraction, instead of *by* the gas through expansion. But if a gas be compressed at constant temperature, and no heat abstracted, work being done on it, and the gas caused to diminish in volume, heat will be stored up, and the temperature of the gas raised. The energy of motion or mechanical work of compression of the particles is transformed into heat. If, however, the heat is carried off in proportion as it is evolved by contraction, the gas will, as has been shown, gradually decrease in volume, in temperature, and in pressure, until the point of absolute zero is reached. In this way the law of the Mechanical Equivalent confirms the existence of an absolute zero. If it were possible for the gas to exceed this limit in any one of its three characteristics, the fundamental law of thermodynamics would be violated. If it could decrease still further in volume, work would be done in contraction without any corresponding diminution in temperature, and we should have energy without heat. The two aspects of the law in its application to gases are, expansion by the addition of heat, and contraction by the withdrawal of heat. In a heat motor the first is called positive, and the second negative work. It is with the effect produced by external work, that the theory and practice of heat engines is chiefly concerned.

Thermal Units.—The proportion between the heat added and work done being a fixed quantity, it is possible to determine accurately the work theoretically performed for a given amount of heat supplied. The two are linked together in practice, and the relation in which they stand to each other is expressed in the following way:—In England it is usual to adopt as the unit of Heat the "British Thermal Unit" (B.T.U.), or the amount of heat which will raise 1 lb. water 1° F., and if this unit of heat be applied to a body, it is equivalent to the work of lifting 778 lbs. 1 foot in height, or a weight of 1 lb. a distance of 778 feet. On the Continent the unit of heat is called a "*calorie.*" One *calorie* raises the temperature of 1 kilogramme of water 1° C., and if this quantity of heat be converted into work, it will lift 425 kilos. through 1 metre, or 1 kilo. through 425 metres. The unit of measurement of work is called foot-pound in England (ft. × lb.), and a kilogrammetre abroad (kilo. × metre). The difference lies only in the respective units of weight and temperature employed here and on the Continent.

The measurement of the exact proportions between heat and work was determined by James Prescott Joule, after long and careful experiments. The apparatus he principally made use of to verify the law of the mechanical equivalent consisted of a closed copper vessel filled with water. Within it were revolving paddles attached to a vertical spindle. The spindle and paddles were made to rotate by means of a cord passing over a pulley connected to a weight. When the weight fell, the spindle rotated, causing the paddles to revolve and to agitate the water, and heat was produced by friction between them. The rise in degrees of temperature of the water was found to be exactly in proportion to the distance in feet passed through by the weight, multiplied by the number of lbs. it weighed. From these and many similar experiments with water and gases, Joule deduced his great law.

Specific Heat.—All bodies have not the same capacity for absorbing heat. Those which are heated without changing their physical state require less heat to raise their temperature than bodies which are converted, during the rise, say from liquid to gaseous. A large quantity of heat must, for instance, be imparted to water, because, after it has absorbed a certain amount it ceases to be a liquid, and becomes a gas, steam. Specific heat, is the quantity of heat necessary to vary the temperature of any body through one degree, the quantity of heat required to raise or lower the temperature of an equal weight of water through one degree being taken as the unit. Water is universally adopted as the standard of comparison, and its specific heat being greater than that of most other bodies, their specific heats are expressed in fractions. For example, a B.T.U. represents the amount of heat required to raise 1 lb. of water 1° F., there-

fore, 100 heat units will raise its temperature 100° F. The specific heat of mercury is ·03332. To raise 1 lb. of mercury through 100° F. will require ·03332 × 100° × 1 lb. = 3·332 heat units. The specific heat of mercury is, therefore, about $\frac{1}{30}$ that of the same weight of water, which requires thirty times more heat units to bring it to the same temperature. Specific heat has been ably illustrated by Mr. H. Graham Harris under the similitude of "appetite." *

Further, the specific heat of the same body will vary according to circumstances. If the body remains under stationary conditions, its specific heat will be less than if its condition changes. To return again to the cylinder containing a given volume of gas. As long as the gas remains inert or passive, and its volume does not vary, it possesses a definite specific heat, which being known, the quantity of heat to be added, to raise it to a certain temperature, can be calculated. But if the piston is driven out, by reason of the expansion of the gas which, according to Gay-Lussac's law, increases in volume by $\frac{1}{273}$ for every degree rise in temperature, work will be done, and heat will in consequence be expended. More heat will, therefore, be required to heat the gas—that is, its "heat appetite" will be greater when it has forced out the piston than before. Under the first condition, the heat absorbed by the gas is defined as its "specific heat at constant volume," because, the piston being stationary, neither the volume of the cylinder nor that of the gas has varied. As the piston moves towards the end of the stroke, the volume is increased, and expansion takes place. The heat of the gas is then called its "specific heat at constant pressure," because, while the volume of the cylinder has varied, the pressure over the piston area has been constant. The specific heat of the gas at constant pressure will be higher than at constant volume, and the difference between the two represents the work done per lb. of gas. That is to say, the increase of specific heat in the gas denotes the amount of heat required to maintain the requisite pressure on the piston, and therefore the work it has performed.

The ratio between these two specific heats is of great importance, and has frequently to be employed in calculations of efficiency or mechanical energy in a heat engine. It varies slightly as given by different authorities, but is usually reckoned at 1·39 by foreign, and 1·408 by English writers. The following table, taken from Regnault, Grashof, Ayrton and Perry, and others, gives the specific heats of various gases at constant pressure and constant volume, and their ratio:—

* See Mr. Harris's Cantor Lectures on "Heat Engines other than Steam," delivered before the Society of Arts, May, 1889, to which the student is referred for an exceedingly clear elementary treatment of the subject.

TABLE OF SPECIFIC HEATS OF GASES (from various Authorities).

	Specific Heat at Constant Volume.	Specific Heat at Constant Pressure.	Ratio.
Air at ordinary temperature, . .	0·168	0·237	1·41
Dry air (Rankine's constant), . .	0·169	0·238	1·40
Steam, ...	0·369	0·480	1·30
Hydrogen, ...	2·406	3·409	1·41
Nitrogen, ...	0·173	0·243	1·41
Oxygen, ...	0·155	0·217	1·40
Carbonic oxide, ...	0·173	0·245	1·41
Carbonic acid, ...	0·171	0·216	1·26
Methane, ...	0·470	0·593	1·26
Mixture of Air and gas—12·26 vols. air to 1 of gas, ...	0·196	0·268	1·37
Products of combustion (vols. before combustion, 1 : 8·18), . . .	0·192	0·264	1·37
Coal gas diluted with 5·76 vols. air, 4·5 vols. products—before combustion, ...	0·182	0·249	1·38
Coal gas diluted with 5·76 vols. air, 4·5 vols. products—after combustion, ...	0·188	0·258	1·36

This ratio, 1·4, is usually expressed by a symbol, which we will call γ. The symbol (x) represents the difference between the specific heat of the gas at constant volume and that at constant pressure. For example, for air $0·237 - 0·168 = 0·069$ B.T.U. equals the increase in the specific heat at constant pressure, when external work has been done, over that at constant volume, when no such work has been done.

The foregoing laws and their results show the way in which mechanical work is obtained in a heat engine. The whole principle of converting heat into work depends on the heat added to the gas, and its effect upon the volumes and pressures. Theoretically, the greater the quantity of heat added, the more work will be done on the piston, because the pressure will be higher, and expansion greater. But to obtain a maximum of work, all sources of waste must be guarded against. The temperature of the gas should, at the outset, be raised to its highest limit, as much heat as possible utilised in expansion, and as little as possible wasted. It is necessary to have at our disposal a source of heat and a source of cold, the one to impart, the other to withdraw the heat. These conditions bring us to the second law of thermodynamics, known as Carnot's, because it was first laid down by him in 1824. It is as follows:—

Carnot's Law.—II. If heat is exchanged at constant temperature between a source of heat and a source of cold, the proportion between the quantity of heat furnished and that abstracted depends only on the absolute temperatures (Centi-

grade + 273°), and not on the nature of the body to which the heat is imparted. The expression "constant temperature" means, not that the amount of heat present does not vary, but that it varies only in proportion to the work done, so that the temperature is not affected. This law, when applied to the phenomena in a heat engine, results in what is called a "perfect cycle." It supposes the whole difference of temperature between the "heat" source and the "cold" source to be utilised in doing work, and no heat to be carried off and wasted, a condition of things, of course, impossible in practice.

But where, it will be asked, is the necessity for a source of cold? Since the more heat is added to a gas, and absorbed in expansion, the more work will be done, why should not the whole of the imparted heat be thus utilised, and none remain to be withdrawn? The reason is that, as there is an absolute zero to which no gas can ever be cooled, therefore the whole heat can never be converted into work. In a motor driven by water falling from a given height, to turn to practical account all the energy stored up in the water, it should fall to the centre of the earth! As it can only descend a given distance, from whatever height it may come, only a certain proportion of its energy can be utilised. The same law applies to the fall in temperature of a heat engine. It is only within certain limits that this range of temperature can be varied, but the wider the limits, the greater the force or energy obtained. To enlarge these limits as much as possible, heat must be added, and the temperature of the working agent raised at the beginning.

This fall in temperature of a gas, and the corresponding loss in pressure upon the piston, takes place inside the cylinder of a heat engine. To calculate the work done, it is very desirable to have a record of the actual pressures during the forward stroke. This is obtained by an instrument called an indicator, which is placed in direct communication with the cylinder, and gives a diagram marking on paper the varying pressures. The curve traced first rises abruptly, marking the sudden rise in pressure due to explosion at constant volume, and then falls gradually with increase of cylinder volume, showing how the pressures slowly decrease as the piston is driven out. To exhibit clearly the proportions between the loss of heat and pressure and the work done during the changes in the gas, two theoretical curves are used.

1. The first is known as the **Isothermal**, and signifies from its name the curve of equal temperatures. Here the piston of a cylinder moves out, by the expansion of the gas produced by the addition of heat, and the effect of the expansion is represented by a curve in which the temperature is constant, and the pressure alone falls. It has been proved that, where work is done on the piston by a gas, the temperature must fall; the isothermal curve, therefore, is based on the assumption that

heat is added to the gas, to compensate for that lost in expansion. This curve is never obtained in practice, but it is occasionally approached when the process of expansion in a heat engine is reversed, and heat is refunded to the gas by compression. In either case, the volume of the gas varies in inverse ratio to the pressure.

2. The **Adiabatic** is another theoretical curve, representing the fall in temperature when heat is neither added to nor abstracted from the working agent, but expended only in doing work by expansion on the piston. The term is derived from a Greek word signifying "impenetrable," and was first applied by Rankine. The nearer the diagrams of pressure approximate to this curve, the more perfectly will the engine utilise the heat imparted to the gas. If the difference in the specific heat of a gas at constant volume and at constant pressure be taken as representing the heat turned into work, the ratio between the two is graphically shown by the adiabatic curve. Since no heat is added or withdrawn, the temperatures do not enter into the definition, and the curve may be expressed as a function of volumes and pressures, thus $p \times v^{\gamma}$ is constant, or :—The pressures of the gas, multiplied by the volumes, raised to the power of the ratio of the two specific heats, give a constant product.

Carnot's Cycle.—Fig. 105 gives a graphic representation of Carnot's law which, plotted out in the shape of the curves just described, forms a perfect or closed cycle. Here the working agent, after passing through the phases of the addition of heat, expansion, abstraction of heat and compression, is brought back theoretically to its original condition. The processes of heating and cooling can be continuously repeated, or the sequence of operations reversed. The necessity for a source of cold is manifest. If the working agent is a gas, it must be cooled to its initial temperature, and this cannot be accomplished by the work of expansion alone. It has hitherto seldom been found possible in any engine to allow the gases to expand to atmosphere, and thus use in work all the heat generated.

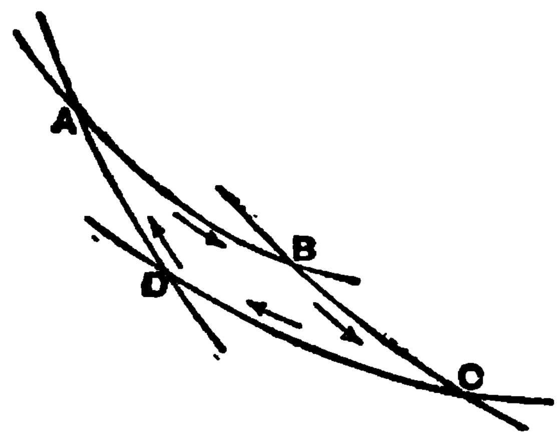


Fig. 105.—Graphic Representation of Carnot's Law.

The cycle (Fig. 105) is formed of two isothermal and two adiabatic curves, and shows their theoretical forms on a small scale. The gas first receives heat from the source of heat, and expands along the line A B with increase of volume. As the temperature is not allowed to fall, the curve is an isothermal. From B to C there is another increase of volume. The gas expands without the addition of heat, the temperature falls in consequence only of work done, and this line shows the curve of adia-

batic expansion. At C communication is opened with the source of cold, and heat is supposed to be withdrawn along the line C D to the same extent as it was added from A to B. The volume is here diminished, and the line C D is again isothermal. From D to A the gas is compressed without heat being abstracted, and consequently increases in temperature, in proportion to the work done upon it. Compression is adiabatic, and at the end of the cycle the gas has returned to its original volume.

Actual indicator diagrams of gas engines do not usually consist of four curves. There is first the line of addition of heat, nearly vertical, then the expansion line, conforming more or less to the adiabatic, and lastly the exhaust, or discharge of the remaining heat to the cold source, which is generally nearly horizontal. (See the diagrams of the various engines.)

It is a condition of the Carnot cycle that heat is only added when the gas is at its highest temperature, before any work has been done, and abstracted at its lowest, after expansion. Since the mechanical energy obtained is in strict proportion to the heat imparted to the working agent, this ideal or typical cycle furnishes and utilises the largest amount of heat. Hirn, the great French *savant*, says:—"It must be evident that this closed cycle has been designed to afford a maximum of work. The heat given up by the source of heat has been employed solely to produce work, and a maximum has therefore been obtained. The heat sent on to the refrigerator has been evolved as economically as possible, since the work has produced no variation of temperature. The object of the other two operations (along the curves C D and D A) has been solely to cause a fall and a corresponding rise in the temperatures and pressures." Thus the cycle obtained is perfect, since the heat supplied from the source of heat and by compression, is equal to the heat expended during expansion and conveyed to the refrigerator. Therefore the working agent or gas is at the close of the cycle in the same condition, that is, at the same temperature and pressure, as at the beginning. Clearly the source of heat and the refrigerator act by alternately expanding and contracting the working agent or gas.

Carnot's Formula.—This cycle may be expressed by the following formula, in which Q represents the quantities of heat supplied by the source of heat, and q the quantities passed on to the source of cold, or in other words, rejected because they cannot be utilised. T_1 is the absolute highest, and T_0 the absolute lowest temperature, and E what is called the theoretical efficiency of the engine:—

$$E = \frac{Q - q}{Q} = \frac{T_1 - T_0}{T_1} = 1 - \frac{T_0}{T_1}$$

On this theoretical basis the heat efficiency is calculated between the highest and lowest temperatures.

Numerical Example.—In the Atkinson 9 H.P. engine, tested by the Committee of the Society of Arts in 1888, the temperature of the gases (Fahr.) on entering the cylinder was 576° absolute (T_0), and their temperature at the moment of highest explosion 2990° absolute (T_1). The theoretical formula of efficiency is—

$$E = \frac{T_1 - T_0}{T_1} = \frac{2990^\circ - 576^\circ}{2990^\circ} = 0{\cdot}80$$

The student will here be inclined to ask what, in this simple formula, becomes of the ratios of specific heats at constant volume and pressure, the coefficient of expansion, and the other complex attributes of expanding gases already described. They are here expressed in their simplest forms, and nothing is taken into account except the quantities of heat, and the temperatures. Now the temperatures in a heat engine must, except the initial temperature of the gases, be deduced from the pressures and volumes. It is in making these calculations that the specific heat of the gases under different conditions, the ratio of expansion to increase of temperature, and other modifying circumstances have to be considered. To calculate the work of an actual engine four or five temperatures, with their corresponding variations of volumes and pressures, must be determined and calculated from experiment. The above formula gives the method of calculation, not the process by which it has been arrived at.

Ideal Efficiency.—Both the highest and lowest temperatures, T_1 and T_0, in a heat engine, and the maximum amount of work which may be obtained from it, are restricted within certain limits. Even in this perfect cycle, it has been proved to be impossible for the lowest temperature, T_0, to fall below a given point. The highest, T_1, is almost as rigidly defined by the phenomena of dissociation, the power of the cast-iron cylinder and the lubricant to resist great heat, and other circumstances. A perfect engine, therefore, is not one giving unlimited expansion, and 100 per cent. of work, but one which turns all the heat supplied to it between the limits T_1 and T_0 into work. This is its maximum utilisation of heat, or what is called the "ideal efficiency" of the engine, which we will now compare with the practical efficiency, or the amount of heat a working engine can actually convert into motive power.

To obtain the highest efficiency, an ideal engine must be supposed to work with—1. A perfect gas, the volumes and pressures of which conform to the laws of Boyle and Gay-Lussac. A study of the chemical constituents of gases, and their action during combustion, shows that this conformity is never obtained in the cylinder of a gas engine. 2. No friction of the working parts. Friction generates heat, and heat we know is the equivalent of energy. Part, therefore, of the mechanical energy of the motor, which in an ideal engine cannot be taken into account,

is absorbed to produce this heat. 3. No radiation or conduction of the heat through the walls of the cylinder containing the gas. Of course it is impossible to have a vessel of this nature—that is, an absolute non-conductor of heat. As soon as the gas is at a higher temperature than the surrounding atmosphere, a certain portion of the heat must be transmitted by radiation to the colder external air. 4. Lastly, expansion must be prolonged till the temperature and pressure of the gases is the same as at admission. This is also impossible. The temperature of the gases is always much higher than T_0, and therefore much heat is discharged at exhaust.

Other Cycles.—In the diagram shown at Fig. 105 the curves A B C D enclose an area representing not only the heat supplied, but the amount of work done by a heat engine. The curves, and therefore the shape of the area, may however vary according to the way in which the heat is supplied to, and withdrawn from, the engine, or according to the expansion and compression of the charge. Figs. 106 and 107 represent two other

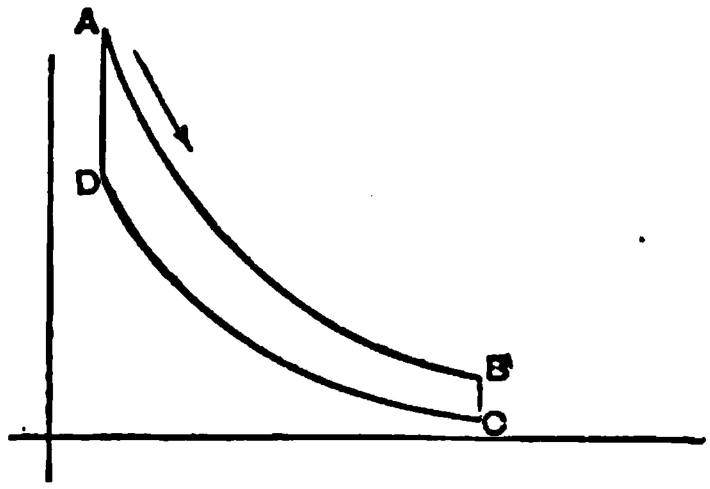


Fig. 106.—Constant Volume.

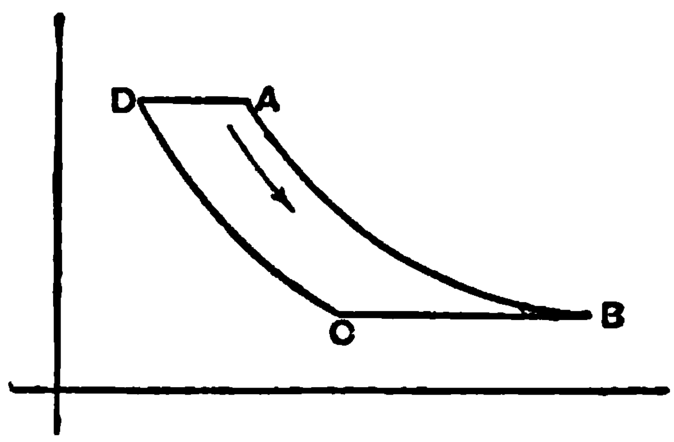


Fig. 107.—Constant Pressure.

theoretical cycles known, the first as Stirling's, the second as Ericsson's. Though the curves are here of different lengths they are, like those forming Carnot's cycle, theoretically perfect, and form the boundaries of an equal area. Heat is added in both cycles from D to A, and abstracted from B to C, and these lines are designated by Professor Witz "isodiabatic," or lines of equal transmission of heat. The curves A B and C D are no longer adiabatic, but isothermal. The first represents the whole of the useful conversion of heat into work at constant temperature; in the second the heat is refunded, and the same amount restored to the gas by compression as was expended in work. The lines B C and D A are straight, parallel in the one case to the vertical line, called an ordinate, at the left hand of Fig. 106, and in the other to the horizontal line (abscissa) at the bottom of Fig. 107. The areas enclosed within these curves form the bases of calculation of all diagrams representing work done in any heat engine. The ordinates in a diagram are in proportion to

the pressures in the cylinder, the abscissæ to the length of stroke.

The horizontal lines in these figures represent the volumes of the cylinder. Along this line the piston may be said to travel, driven forward by the expanding force of the gas, and the farther it moves to the right the larger the cubic contents of the cylinder. If the piston is moved half way along the horizontal line, half the volume of the cylinder, reckoning from the dead point, will be uncovered by it. The horizontal line in an indicator diagram, therefore, represents volumes of the cylinder or lengths of stroke, and distances along it are calculated in feet or metres. The vertical line in the figures, and in indicator diagrams of heat engines, represents the pressures of the gas obtained by the addition of heat, and is usually divided into sections reckoned as so many lbs. pressure per square inch of piston surface. So that we get horizontally *feet*, and vertically *lbs.*, or ft. × lbs. = work in proportion to area of diagram.

Indicator Diagrams.—It will make the study of the heat engine easier to the student if we describe here how an actual indicator diagram is taken, and the kind of instrument used to trace it. The same type of apparatus is employed in gas as in steam engines. It consists of a small piston and cylinder in direct communication with the inside of the motor cylinder; the piston is forced up or down with the varying internal pressures produced by the expansion of the gas. To the upper part of this piston is attached a small pencil. A drum covered with paper is made to travel to and fro at the same relative speed as the motor piston. The apparatus is so arranged that as the drum moves horizontally, the pencil of the indicator piston moves vertically. The pencil goes up and down in proportion to the cylinder pressures (lbs.) and the paper travels to and fro in proportion to the stroke (ft.) These two movements are brought in contact, and the pencil traces a diagram on the paper (see Fig. 110, p. 246). The vertical lines of this diagram represent lbs. pressure per square inch on the piston surface, and the horizontal lines feet travelled through by the piston.

The pressures and the volumes of a gas being known from the indicator diagram, the temperatures are usually calculated from them. To determine these temperatures in a gas engine is, however, a difficult process, because many scientific men are of opinion that, at the moment of explosion, the gases in the cylinder are not at a uniform temperature throughout. In the two closed cycles given in Figs. 106 and 107 the lines of addition and abstraction of heat, D A and B C, are in the first figure parallel to the pressures, in the other to the volumes. This means that in Fig. 106 the heat is supposed to be added from the source of heat and withdrawn, while the volume remains constant, and the piston stationary at either end of the cylinder.

In Fig. 107 the heat is added and abstracted while the pressure of the gas remains constant, the piston being forced out, and the volume of the cylinder increased. More heat must be added for a given rise of temperature than in the other case, because a certain amount is expended in driving the piston. The two figures exhibit, under another form, the ratios of specific heat at constant volume and at constant pressure.

It is from the indicator diagram, therefore, or diagram of pressures, that it is possible to know theoretically how much heat enters an engine (Q) and how much leaves it (q), and to determine

$$\text{Efficiency} = E = \frac{Q - q}{Q}$$

But this formula will not express the actual work done, or at least the determinations of Q and q will, under these conditions, be a matter of great difficulty. Some of the various deficiencies in the cycle of a working engine have already been mentioned. There has hitherto always been a wide discrepancy between the theoretical possibilities of a heat motor, and the actual results. To discover the reason of this difference, complete investigations and experiments are necessary. Not only do we need to know the total amount of heat supplied to an engine, and what becomes of it, but how and when the heat is added. Science has already done much to elucidate the first point; our knowledge of the second is still elementary.

Entropy and Entropy Diagrams.—The following account of this abstruse subject is taken from an article by the author in *Engineering*, 3rd January, 1896, forming part of a translation of a paper by Professor J. Boulvin of Ghent University :—

In the calorimetric study of any engine, the exchanges of heat taking place between the fluid and the internal walls of the cylinder should be determined, and for this process the graphic method will be found of great use. For instance, the heat supplied to the cylinder being represented by a given area, the latter may be divided into several parts, one of which will represent the heat converted into work on the piston, another the heat given up to the walls, or dissipated in other ways, and thus a kind of graphic heat balance is obtained. If the heat not utilised in work be further subdivided into its component parts, or into loss of heat due to the water jacket, to the exhaust, and to radiation, it will be possible to show exactly how the heat supplied to the engine has been expended.

The indicator diagram, which gives changes of pressures and volumes, cannot be used for this purpose, since the area thus obtained marks only the work done on the piston. To show the movements of heat, they must be converted by calculation into mechanical energy for each portion of the stroke, and this is the

way in which the subject has lately been treated by various scientific authorities. The new system furnishes a direct graphic representation of the heat supplied to a body, by taking temperature and entropy as the characteristics of its condition. For ordinary purposes, it will be sufficiently clear if the following explanation of the term "entropy" be accepted:—

Let us suppose that an infinitesimal quantity of heat, $d\,Q$, is supplied to a body at the absolute temperature, T; the increase of entropy in this body is defined as $\frac{d\,Q}{T}$, or entropy multiplied

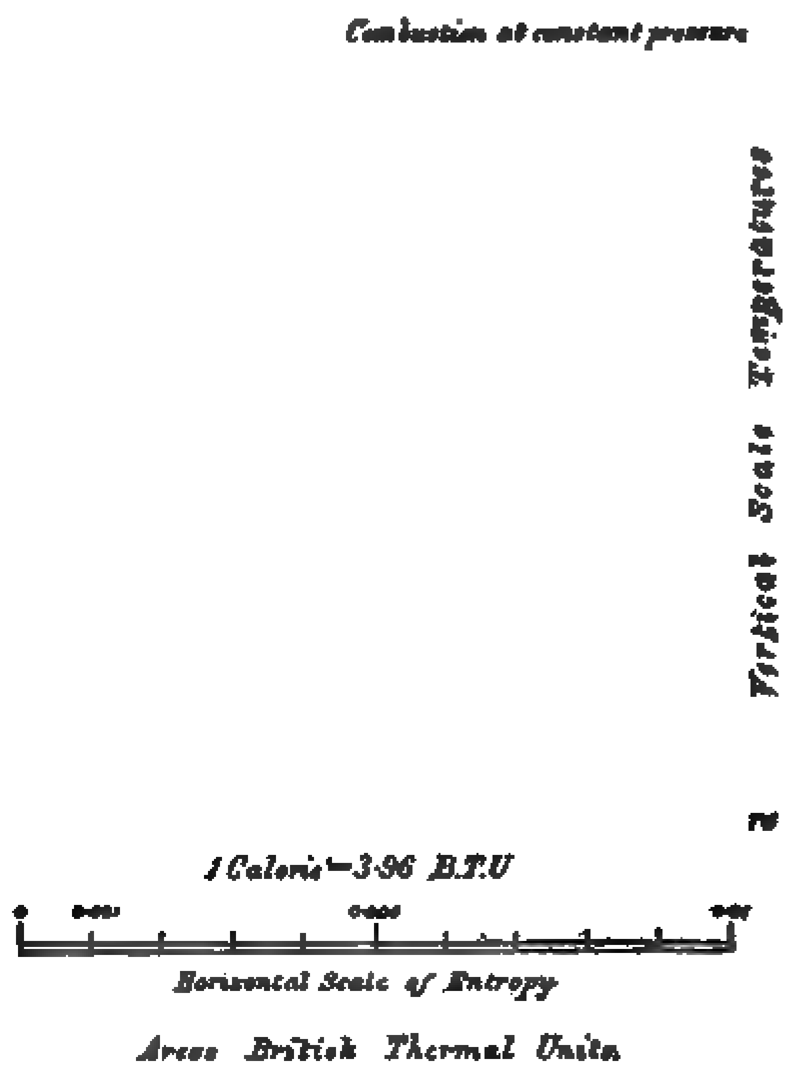


Fig. 108.—Entropy diagram.

by absolute temperature equals number of calories. Thus $\frac{d\,Q}{T}$ may be considered as a weight which, falling from the height T, will produce the energy $d\,Q$, since $\frac{d\,Q}{T} \times T = d\,Q$. If the increase or successive additions of $\frac{d\,Q}{T}$ be plotted as abscissæ, and the different absolute temperatures, T, as ordinates, a curve

will be obtained, the area of which will represent the sum of all the elements d Q,—that is, the heat supplied. The movements of heat can be deduced from the particular form of the curve thus obtained. Thus if the fluid studied is the mixture of gas and air expanding in a cylinder, the curve will show by its shape if the heat is passing from the mixture to the walls, or in the reverse direction.

An example of the entropy diagram, as applied to a gas engine, taken from Professor Boulvin's book,* is given at Fig. 108. It is a diagram of Entropy, or Heat, worked out from the Society of Arts' Trials, 1888, on a Crossley-Otto engine, and should be compared with the indicator diagram at p. 93. The latter, sometimes called the p V diagram, is necessary to get the I.H.P., and upon it and other data the entropy diagram is based, but the I.H.P. diagram gives no results for exchanges of heat and temperature, which are so important to investigate, and it is not a complete index of what takes place in an engine cylinder. The area of an entropy diagram gives thermal units. For the method of drawing it see the paper already referred to, and M. Boulvin's book, vol. iii., p. 41. Captain Sankey determines each point from the intersection of the lines of equal pressure and equal volume. The term "entropy" was first adopted by Clausius to denote the integral $\frac{d\,\mathrm{Q}}{\mathrm{T}}$. The method of drawing entropy diagrams is first claimed for M. Belpaire in 1872, and is described by Schöttler (p. 206) who lays down clearly the difference between the diagrams of heat and of pressure, and by Professor Zeuner. In England the subject has been treated by Mr. Macfarlane Gray, who calls entropy the $\theta\,\varphi$ diagram.†

* *Cours de Mécanique Appliquée*, vol. iii., p. 173 (*Machines Thermiques*).
† See *Proceedings Institution Mechanical Engineers*, July, 1889.

CHAPTER XVII.

THE CHEMICAL COMPOSITION OF GAS IN GAS ENGINES.

CONTENTS.—Atoms and Molecules—Chemical Symbols—Atomic Weights—Molecular Weights—Specific Heat—Chemical Equations—Heat of Combustion of Gas—Calorimeters—Composition of Coal Gas—Calorific Value of Coal Gas, and of other Gases—Heat of Combustion of Gases.

IN the preceding chapter we have seen that a gas engine is simply one form of heat engine, and that its object is to transform heat into work through the medium of gas—the working agent. We now want to know, further, how this process is carried on with maximum efficiency, so that the largest possible proportion of the whole heat we add to the agent may be converted into useful work.

We must, therefore, examine more closely into the nature, composition, and specific properties of the gas employed.

The object of this chapter is to determine—

1. What coal gas is;
2. How much air is required to burn it;
3. How much heat is given out during combustion, and carried away by the residual gases.

As the nomenclature adopted by chemists renders the treatment of the problem of combustion of gases very simple, it will be convenient to begin with a brief explanation of its main principles.

Atoms and Molecules.—All apparently homogeneous substances are composed of extremely small particles, called *molecules*, which, for any given substance, have the same weight.

These molecules, which are the smallest particles of the substance which can exist in the free state, are, in general, composed of still smaller particles, called *atoms*. If all the atoms in the molecules are identical, the substance is known as an *element*, inasmuch as in this case, it is not possible to break it up into two or more distinct bodies. If, on the other hand, two or more different kinds of atoms exist in the molecule, it is known as a *compound*.

The fundamental law upon which chemistry at the present day is based, first enunciated by Avogadro, is—"Equal volumes of gases (under the same conditions of temperature and pressure) contain equal numbers of molecules."

There is another way of stating this, which is sometimes useful. Take a cubic foot of any gas, say oxygen, at a fixed temperature and under a fixed pressure. It contains n molecules, where n is a very large number, only roughly known, and the exact value of which is not required here. The *average space* occupied by a molecule of oxygen then, is $\frac{1}{n}$ cubic feet. This is called the "molecular volume" of oxygen. Now, since the same volume of any other gas, say hydrogen, by the law first enunciated, also contains n molecules, its molecular volume is also $\frac{1}{n}$ cubic feet. Hence, another way of stating Avogadro's law is—"All gases have the same molecular volume."

To resume then—

1. All atoms of the same element have the same weight.
2. All molecules of the same compound have the same weight and the same volume.

Chemical Symbols.—As an abbreviation for one atom of an element, the first letter or first two letters of the word is used; thus, C stands for an atom of carbon, H for an atom of hydrogen, O for an atom of oxygen, N for nitrogen, S for sulphur, and so on. Two letters placed together represent a molecule of a compound; thus, CO denotes one molecule of the compound carbonic oxide, formed by the combination of one atom of carbon C, and one atom of oxygen O. Similarly CO_2 denotes a molecule of the compound carbonic acid, containing three atoms, one of carbon and two of oxygen. $2CO_2$ denotes *two* molecules of carbonic acid.

Atomic Weights.—Now the actual weights of the atoms are excessively minute, and are only known very roughly indeed. But the *relative* magnitude of the weights of the atoms of the various elements can be, and has been determined with very considerable accuracy. It is customary to take the weight of the lightest known atom, hydrogen, as unity; and the values for "atomic weight" found in works on chemistry, represent the weights of the atoms of the various elements as multiples of this.

All the gaseous elements dealt with here contain two atoms in each molecule. Thus H_2, N_2, O_2 are the molecular formulæ for the elementary gases—hydrogen, nitrogen, oxygen respectively. From this, and with Avogadro's law, it is easy to find the atomic weights of nitrogen and oxygen. It is found that 1 cubic foot of hydrogen weighs ·005591 lb. under standard conditions of pressure and temperature, 1 cubic foot of oxygen weighs ·089456 lb., and of nitrogen, under the same conditions, ·07828 lb. These numbers are in the ratio of 1 : 16 : 14. Hence, if $nH_2 = 1$ unit of weight, by Avogadro's law the same

number $nO_2 = 16$ units of weight, and $nN_2 = 14$ units of weight—*i.e.*, the atomic weights of hydrogen, oxygen, and nitrogen are as 1 : 16 : 14. The only atomic weights required in this chapter for gas engines are:—

TABLE OF ATOMIC WEIGHTS.

Element.	Hydrogen.	Oxygen.	Nitrogen.	Carbon.	Sulphur.
Symbol, . .	H	O	N	C	S
Weight of atom (in round numbers)	1	16	14	12	32

Molecular Weights.—The "molecular weight"—*i.e.*, the total weight of each molecule, when the hydrogen *atom* is the unit of weight, is obtained by simply adding together the weights of its constituent atoms. Thus the molecular weight of hydrogen, H_2, is 2; of oxygen, O_2, is 32; of carbonic oxide, CO, $12 + 16 = 28$; of marsh gas, CH_4, $12 + (1 \times 4) = 16$. Hence the weight of 1 cubic foot of hydrogen being ·00559 lb., that of a cubic foot of carbonic oxide is $\left(\frac{16 + 12}{2}\right) = 14 \times \cdot 00559$; of marsh gas, $\frac{4 + 12}{2} = 8 \times \cdot 00559$; and so on for any other gas.

Specific Heat.—If a quantity of heat is added to a gas it may result in an increase of pressure, temperature, or volume, or in an increase of all three. Thus, there may be several "specific heats." The only two generally used are:—

(1) The specific heat at constant volume, which is defined as the number of units of heat required to raise the temperature of the unit weight of gas through 1°, the volume of the gas remaining constant; and

(2) The specific heat at constant pressure, where the gas is allowed to do work by expanding.

Of these the former, which is obviously the smaller number, is sometimes termed the "true specific heat," all the heat going in this case to increase the internal energy of the gas.

For the elementary gases, hydrogen, oxygen, and nitrogen, and also for carbonic oxide, it is found that the amount of heat required to raise equal volumes through 1° is very nearly the same; or, in other words, that the specific heat × molecular weight = constant. It is also found that the specific heats are nearly independent of the temperature, tending only to increase very slightly with it. For the more complicated molecules, such as marsh gas, CH_4, ethylene, C_2H_4, &c., which occur in

coal gas, neither of these relations hold, the amount of heat required to raise, say 1 cubic foot of ethylene through 1°F., is sensibly different from that required to raise the same volume of air through 1°F., and, further, the specific heat increases very rapidly with the temperature.

The table of specific heats will be found on p. 217.

Chemical Equations.—Chemical equations are symbolic representations of chemical changes. It will be convenient to take one equation as a type and explain it in detail. The following is a useful example:—

$$\underset{\text{Methane.}}{\underset{(12+4)}{CH_4}} + \underset{\text{Oxygen.}}{\underset{2(32)}{2O_2}} = \underset{\text{Carbonic Acid.}}{\underset{(12+32)}{CO_2}} + \underset{\text{Steam.}}{\underset{2(2+16)}{2H_2O}}$$

This is interpreted as follows:—Since 1 *molecule* of methane combines with 2 *molecules* of oxygen, it follows, by Avogadro's law, that 1 *volume* of methane combines with 2 *volumes* of oxygen, giving 1 *volume* of carbonic acid and 2 *volumes* of steam. This same equation also expresses the fact that 16 lbs. of methane require 64 lbs. of oxygen for complete combustion, and give as the resulting products 44 lbs. of carbonic acid and 36 lbs. of steam. By the term "complete combustion" is meant that the hydrocarbon combines with the maximum possible amount of oxygen, giving carbonic acid and water only as the final products.

When the quantity of oxygen required for the combustion of each constituent is known, the next step is to determine the heat evolved by combustion. As this heat cannot be measured in the cylinder of an engine, the calorimetric value of the gas is obtained by burning it in oxygen. For this purpose an instrument is employed, called a calorimeter. MM. Favre and Silbermann were the first to design an apparatus for testing the heating values of solid, liquid, and gaseous fuels, and other calorimeters have since been brought out.

Heat of Combustion of Gas.—The amounts of heat developed by the complete combustion of the various carbon compounds contained in coal gas, have been experimentally determined in two ways. Firstly, by burning a current of the gas in question in oxygen or air at the ordinary atmospheric pressure, and, secondly, by exploding a mixture of the two gases in a strong steel "bomb."

The advantages of the second method, which was first used by Andrews, and has been recently employed in an improved form by M. Berthelot and M. Mahler, are that the combustion takes place at constant volume, and that, on account of the much shorter time occupied by the reaction, the "corrections for cooling" of the calorimeter are very much reduced.

One gramme of the fuel, the heating value of which is to be determined, is introduced into the closed vessel or bomb, placed within an outer shell filled with water. Pure oxygen is then admitted to the inner vessel at a pressure of 25 atmospheres, the mixture is instantaneously fired by the electric spark, and the rise in temperature of the surrounding water shows the heat evolved during combustion. Extremely delicate thermometers are used, marking the rise in temperature to within $\frac{1}{100}$ of a degree. M. Berthelot lined his calorimetric bomb with platinum, to resist the heat. This metal is very costly, and a less expensive calorimeter has been introduced by M. Mahler, in which the "bomb" is of steel lined with enamel, but it is similar to Berthelot's design in other respects. Mr. C. Wilson has, in his calorimeter, substituted gilding for enamel, with excellent results, as it is not so expensive and wears better. The enamel chips off in time, and the steel underneath then rusts.

Two new gas calorimeters have lately been introduced, especially designed for measuring the heating value of gases. The first, by Junkers of Dessau, is based on the principle of the rise in temperature of a current of water in a tank, passing over a gas jet. The apparatus consists of a vertical cylindrical vessel, with considerable heating surface, a burner beneath connected to a small accurate gas meter, and an arrangement for regulating the pressure of the gas. The water from a nozzle enters the calorimeter at the bottom and passes out at the top, the temperature both at the inlet and outlet being taken by sensitive thermometers. A third thermometer gives the temperature of the products of combustion, and a fourth that of the gas on leaving the meter. A Bunsen burner is used for testing town gas, and an ordinary metal tube for poorer kinds; the size of the flame is regulated, and is larger the lower the heating value of the gas. The calorimeter is first filled with water, the burner introduced, and the difference in temperature between the water passing in and out is read off from the thermometer. The quantity of water is measured by a gauged vessel. The lbs. of water, its rise in temperature, and number of cubic feet of gas burnt being known, the heating value of the gas can be calculated. This instrument seems to be much used in Germany, and has been tested by competent authorities. The author has seen it at work, and trials can be made with it accurately and quickly.

The Dowson calorimeter is constructed on the same principle of measuring the heating value of a gas by its combustion, and the rise in temperature produced in a given quantity of water. It is rather simpler, with fewer parts, and like the Junker, it uses a Bunsen burner for burning the gas. The calorimetric

vessel is made of lacquered brass. This apparatus has only recently been brought out.

With the help of a calorimeter, the heat of combustion of coal and other fuels, solid and liquid, and of most kinds of combustibles, has been determined. The following table gives the values, by different authorities, of the heat produced by the combustion of the chemical constituents of coal gas, and also of solid carbon :—

HEAT PRODUCED BY THE COMBUSTION OF H, C, CO, &c. (from Ostwald's *Verwandtschafts-Lehre*, 1887).

Unit Weight or Gramme of	Units of Heat evolved by Complete Combustion of 1 gramme at 17° C., and Atm. Pressure.			
	Favre and Silbermann.	Thomsen.	Berthelot.	Thomsen.
	Cal.	Cal.	Cal.	B.T.U.
Hydrogen, H, . . .	34,460	34,180	34,600	61,560
Carbon, C, . . .	8,080	8,080	8,138	14,540
Carbonic oxide, CO, . .	2,403	2,429	2,439	4,372
Marsh Gas, CH_4 . .	13,062	13,244	13,344	23,850
Ethylene, C_2H_4, . .	11,857	11,907	12,193	21,430
Benzene, C_6H_6, . .	9,915	10,249	9,949	18,448

That is to say, 1 gramme of carbon completely burnt gives out sufficient heat to raise 1° C. the temperature of 8,080 grammes of water from and at 17° C., or 1 gramme water 8,080° C. according to Favre and Silbermann's reckoning. MM. Berthelot and Mahler claim to have obtained more accurate results with their calorimeters, owing to the more rapid and complete method of combustion; their values are slightly higher.

The following table shows the number of British thermal units given out by the complete combustion of 1 cubic foot of each of the gases usually present in coal gas :—

TABLE OF B.T.U. RESULTING FROM THE COMPLETE COMBUSTION OF 1 CUBIC FOOT OF DIFFERENT GASES.

Name of Gas.	Calorific Values per Cubic Foot (measured at 32° F. and 30 ins. pressure of Mercury) in B.T.U. (British Thermal Units).
Hydrogen, ...	293·5
Carbonic oxide, . . .	342·3
Methane, ...	1,066
Ethylene, ...	1,678
Propylene, ...	2,479
Butylene, ...	3,275
Benzene, ...	4,023

(To be quite accurate, these values must be multiplied by a factor obtained from the temperature and barometer height at the time of experiment.)

The unit of heat used here is the amount of heat required to raise 1 lb. of water, at 64° to 68° F., 1° F. The difference between the specific heats of water at 0° C. and water at 19° is only about 1 in 1,000. The products are supposed to be cooled down to about 19° C. As the figure given for hydrogen includes the latent heat of steam, it may be replaced by the figure 52,500,* in which this latent heat remains in the steam gas.

Composition of Coal Gas.—As regards the actual composition of coal gas, the following table, taken from Schöttler, shows an average composition of 1 cubic foot of ordinary Hanover lighting gas, distilled from coal in retorts, without admixture of air:—

TABLE SHOWING AVERAGE COMPOSITION OF 1 CUBIC FOOT OF HANOVER COAL GAS (*Schöttler*).

Volume.	Name of Gas.	Chemical Symbol.
Cubic Feet.		
·0069	Benzene.	C_6H_6
·0037	Butylene.	C_4H_8
·0211	Ethylene.	C_2H_4
·3755	Methane.	CH_4
·4627	Hydrogen.	H_2
·1119	Carbonic oxide.	CO
·0081	Carbonic acid.	CO_2
·0101	Nitrogen.	N_2
1·0000		

The first three gases are called "heavy hydrocarbons," and as they are all frequently absorbed together by the same reagent (fuming sulphuric acid), they are generally included together under one head.

* 52,500 B.T.U. in 1 lb. H., ∴ 52,500 × 0·00559 (weight 1 cubic foot H. per lb.) = 293·5.

Benzene, C_6H_6, burns with excess of oxygen as follows:—
Molecular weight, 78; weight of 1 cubic foot = 39 × ·005591 = ·2181 lb.

$$^*C_6H_6 + 7\tfrac{1}{2}O_2 = 6CO_2 + 3H_2O$$
$$(1 \text{ vol.}) + (7\tfrac{1}{2} \text{ vols.}) = (6 \text{ vols.}) + (3 \text{ vols.})$$

Butylene, C_4H_8 (Synonym—Tetrylene).

$$C_4H_8 + CO_2 = 4CO_2 + 4H_2O$$
$$(1 \text{ vol.}) + (6 \text{ vols.}) = (4 \text{ vols.}) + (4 \text{ vols.})$$

Molecular weight, 56; weight of a cubic foot, 28 × ·005591 = ·1566 lb.

Ethylene, C_2H_4 (Synonyms—Olefiant gas, ethene).

$$C_2H_4 + 3O_2 = 2CO_2 + 2H_2O$$
$$(1 \text{ vol.}) + (3 \text{ vols.}) = (2 \text{ vols.}) + (2 \text{ vols.})$$

Molecular weight, 28; weight of a cubic foot, 14 × ·005591 = ·0783 lb.

Methane, CH_4 (Synonyms—Marsh gas, firedamp).

$$CH_4 + 2O_2 = CO_2 + 2H_2O$$
$$(1 \text{ vol.}) + (2 \text{ vols.}) = (1 \text{ vol.}) + (2 \text{ vols.})$$

Molecular weight, 16; weight of a cubic foot, 8 × ·005591 = ·044728 lb.

Hydrogen, H_2.

$$^*H_2 + \tfrac{1}{2}O_2 = H_2O$$
$$(1 \text{ vol.}) + (\tfrac{1}{2} \text{ vol.}) = (1 \text{ vol.})$$

Molecular weight, 2; weight of a cubic foot, ·005591 lb.

Carbonic Oxide, CO (Synonym—Carbon monoxide).

$$^*CO + \tfrac{1}{2}O_2 = CO_2$$
$$(1 \text{ vol.}) + (\tfrac{1}{2} \text{ vol.}) = (1 \text{ vol.})$$

Molecular weight, 28; weight of a cubic foot, 14 × ·005591 = ·0783 lb.

Carbonic Acid, CO_2 (Synonyms—Carbonic anhydride, carbon dioxide).

Molecular weight, 44; weight of a cubic foot, 22 × ·005591 = ·123 lb.

Nitrogen, N_2, does not play any active part in the combustion, but remains unchanged throughout the whole set of operations. It acts as a mere diluent.

Molecular weight, 28; weight of a cubic foot, 14 × ·005591 = ·0783 lb.

Since the whole of the oxygen represented in the above equations has to come from the air, and since there are in the air 79 volumes of nitrogen to 21 of oxygen, it follows that one volume of oxygen must be replaced by about 4·762 of air.

* To be strictly accurate, these equations should be doubled, but the volume relations are more clearly shown as they are. Of course, half a molecule is a physical impossibility.

The preceding data may be conveniently tabulated as follows:—

TABLE SHOWING PRODUCTS OF COMBUSTION OF THE VARIOUS CONSTITUENTS OF COAL GAS.

Name.	Formula.	Density in lbs. per cub ft. at 0° C. and 760 mm. pressure.	Volumes Oxygen required for Complete Combustion.	Volumes of Air.	Volumes CO_2 Produced.
Benzene, . . .	C_6H_6	·2181	$7\frac{1}{2}$	35·71	6
Butylene, . . .	C_4H_8	·1566	6	28·57	4
Ethylene, . . .	C_2H_4	·0783	3	14·28	2
Methane, . . .	CH_4	·0447	2	9·52	1
Hydrogen, . . .	H_2	·00559	$\frac{1}{2}$	2·38	0
Carbonic oxide, .	CO	·0783	$\frac{1}{2}$	2·38	1
Carbonic acid, .	CO_2	·1230	...	...	...
Nitrogen, . . .	N_2	·0783	...	...	...

The composition of lighting gas is not constant. It depends upon the quality of the coal, the temperature of the retort, and the period of distillation. The following table, from experiments by Dr. Wright,* shows the influence of the time that has elapsed after charging the retorts.

COAL GAS.

Constituents.		Time after Commencement of Distillation.		
		10 minutes.	3 hours 25 min.	5 hours 35 min.
Hydrogen, . .	H_2	·2010 per ct.	·5268 per ct.	·6712 per ct.
Marsh gas, . .	CH_4	·5738 ,,	·3354 ,,	·2258 ,,
Carbonic oxide, .	CO	·0619 ,,	·0621 ,,	·0612 ,,
Heavy hydrocarbons, . . .	...	·1062 ,,	·0304 ,,	·0179 ,,
Nitrogen, . . .	N_2	·0220 ,,	·0255 ,,	·0078 ,,
Carbonic acid, .	CO_2	·0221 ,,	·0149 ,,	·0150 ,,
Sulphuretted hydrogen, . . .	SH_2	·0130 ,,	·0049 ,,	·0011 ,,
Cub. ft.		1·0000 ,,	1·0000 ,,	1·0000 ,,

The following table shows the composition of the coal gas in most of the large towns of Europe, &c. :—

* *Journ. Chem. Soc.*, No. 261, 1884.

COMPOSITION OF COAL GAS IN VARIOUS CITIES AND TOWNS,

IN PERCENTAGE BY VOLUME.

Constituents in Gas, Percentage by Volume.	London Gas-Light and Coke Co.	London Society of Arts' Trial.	Manchester.	Kilmarnock Trial, Prof. Kennedy.	Gas-Motoren Fabrik Cologne (Slaby).	Bonn (Clerk).	Dresden (Schöttler)	Hanover (Schöttler).	Hoboken New-York (Brooks & Steward).	Paris (Peclet).	Paris (Witz).
Heavy hydro-carbons, . .	4·41	3·77	6·46	5·55	3·50	4·75	3·00	3·17	6·60	5·80	5·50
Marsh gas, CH_4,	37·64	37·34	34·90	42·80	34·40	43·12	33·40	37·55	37·30	33·10	32·30
Hydrogen, H, .	47·99	50·44	45·58	43·60	56·90	39·80	48·70	46·27	39·50	50·10	52·80
Carbonic oxide, CO, ...	3·75	3·96	6·64	4·30	5·20	4·66	8·00	11·19	4·30	6·30	5·60
Carbonic acid, CO_2, . . .	...	0·51	3·67			3·02	1·50	0·81	2·70 and impurities.	1·50	...
Oxygen, O, . .	0·26	...	... H_2S 0·29	1·05	...	...	1·40	...	1·40	0·50	...
Nitrogen, N, .	5·95	3·98	2·46	2·70	..	4·65	4·00	1·01	8·20	2·70	3·80
Totals, . .	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

Calorific Value of 1 Cubic Foot of any Coal Gas.—From the table of B.T.U., p. 233, it is now easy to find the calorific value of 1 cubic foot of any lighting gas, it being only necessary to multiply the volume percentage of each combustible gas by its calorific power per cubic foot, as given in the second column of that table.

Take for example the following gas :—

Name of Gas.	Volumes in cub. ft.	Calorific Value B.T.U. in 1 cub. ft.	Weight in lbs. per cub. ft.	Volumes Oxygen required.
Methane, ...	·4280	456·2	·019130	·8560
Ethylene, ...	·0277	46·5	·002169	·0831
Butylene, ...	·0278	91·0	·004353	·1668
Hydrogen, ...	·4360	128·0	·002437	·2180
Carbonic oxide, . .	·0430	14·7	·003366	·0215
Nitrogen, CO_2 and O_2, .	·0375	...	·003220	...
	1·0000	736·4	·034680	1·3454

i.e., 1 cubic foot of this gas on complete combustion would yield 736·4 B.T.U., or $\frac{736\cdot4}{\cdot03468} = 21,230$ B.T.U. per lb. of gas, and would require 1·345 volumes of oxygen or 6·407 of air for complete combustion.

As a matter of fact, when 1 cubic foot of this gas is mixed with 1·345 volumes of oxygen, the explosion is so violent as to be quite unmanageable. Even when diluted with nitrogen as in air, the correct proportions for complete combustion (here 6·407 volumes of air to 1 of coal gas) still give too violent an explosion. This can be moderated by using an excess of air which acts as a diluent, lowering the partial pressure of the re-acting gases. This excess of air, together with the whole of the 5·062 volumes of nitrogen introduced with the re-acting oxygen, and the nitrogen originally present in the gas, unavoidably impairs the efficiency, as the whole of this has to be heated up to the temperature of the cylinder gases. Further, it is discharged at a high temperature (about 400° to 450° C.) together with the carbonic acid produced in the reaction, and the whole of this heat is wasted. In the various producer and water gases, formed by forcing air or mixtures of air and steam over red-hot coal, the amount of nitrogen is considerable, and accordingly much less air is required for their complete combustion. Thus, wherever coal gas requires from 6 to 15 volumes of air, Dowson gas requires only 1⅛ volumes.

The following table gives the composition of several of these cheaper gases :—

TABLE OF COMPOSITION OF POOR GASES.

Name of Gas.	Oxygen, O, vol. per cent.	Hydrogen, H, vol. per cent.	Marsh Gas, CH_4, vol. per cent.	Olefiant Gas, vol. per cent.	Carbonic Oxide, CO, vol. per cent.	Carbonic Acid, CO_2, vol. per cent.	Nitrogen, N, vol. per cent.
Producer gas (Siemens'),	...	8·6	2·4	...	24·4	5·2	59·4
Water gas, . . .	0·10	50·50	0·60	...	44·40	1·60	...
Strong gas, . . .	...	53·0	...	...	35·0	4·0	8·0
Lowe gas, . . .	...	30·0	...	...	28·0	34·0	8·0
Dowson gas, . .	0·03	18·73	0·31	0·31	25·07	6·57	48·98
,, . .	0·23	24·36	1·16	0·15	17·55	6·07	50·48
Lencauchez gas, . .	0·50	20·00	...	4·0	21·00	5·00	49·50
Taylor gas, . .	...	12·00	1·20	...	27·00	2·50	57·30

It may be useful, as an example, to work out the calorific value of one of these, say Siemens' producer gas:—

HEATING VALUE OF 1 CUBIC FOOT OF SIEMENS' PRODUCER GAS IN BRITISH THERMAL UNITS.

Gas.	Symbol.	Amount in 1 cub. ft.	Calorific Value per cub. ft.	Calorific Value per cub. ft. of Gas in B.T.U.	Volumes of Oxygen required in cub. ft.	Volumes of Air required in cub. ft.
Hydrogen, . .	H_2	·086	293·5	25·24	·043	·205
Methane, . . .	CH_4	·024	1066·0	26·58	·048	·229
Carbonic oxide, .	CO	·244	3423·0	83·51	·122	·581
Carbonic acid, .	CO_2	·052	...	...	...	...
Nitrogen, . . .	N_2	·594	...	...	...	...
		1·000	...	135·33	0·213	1·015

Hence the calorific power of this producer gas is, roughly speaking, only one-fifth that of an equal volume of coal gas, and it requires only a little more than its own volume of air for complete combustion.

Interesting calculations by A. Naumann on the transformation of heat into chemical energy in the production of power gas will be found in the *Berichte der deutschen chemischen Gesellschaft*, No. 25, 1892. In the formation of producer or air gas, heat is liberated, in that of water gas, it is absorbed, and the author considers how the surplus heat of the one process can be utilised in the other. This may be done either by introducing water with the air for combustion, (as in Dowson gas), thus forming what he calls "water producer gas," or by introducing CO_2 to form carbonic acid producer gas. The following table shows the heating value of these gases, as compared with water gas:—

TABLE OF THE HEAT OF COMBUSTION OF VARIOUS GASES.

Name of Gas.	Heat of combustion of 1 cub. ft., the water produced being assumed to be gaseous at 15° C.	Heat given up by the products of combustion of 1 cub. ft. of the gas in cooling 1° C.
	B.T.U.	B.T.U.
Producer gas, ...	66·2	0·03484
Carbonic acid producer gas, .	110·4	0·04509
Water-producer gas, from liquid water at 15° C., . . .	104·9	0·04455
Water producer gas, from gaseous water at 15° C., . .	113·6	0·04675
Water gas, ...	178·5	0·06308

The same subject has been treated by Mr. Norton Humphreys in a paper on "The Gas Engine, from a theoretical point of view." * Volume for volume, the calorific value of lighting gas increases with its illuminating power. The richer the gas, the greater its specific gravity, but if judged by weight, its quality does not affect the heating value. To estimate the latter accurately, not only the weight, but also the chemical composition of a gas should be known. Mr. Humphreys calculates the equivalent in motive power of—

15-candle gas at	620 B.T.U.	× 772 ft.-lbs.	= 478,640 ft.-lbs. per cub. ft.		
19- „ „	800 „	× 772 „	= 617,600 „ „		
28- „ „	950 „	× 772 „	= 733,400 „ „		

The following table is taken from Mr. Dugald Clerk's paper on "Recent Developments in Gas Engines," in the *Proceedings of the Institution of Civil Engineers*, vol. cxxiv., 1895-1896. It is calculated from an analysis by Dr. P. F. Frankland in a paper read before the Society of Chemical Industry, 5th May, 1884, and gives the weight, volume, and heating value of lighting gas in most of the large towns in England and Scotland :—

* *Gas Engineer's Annual*, 1889.

DATA CALCULATED FROM DR. P. F. FRANKLAND'S ANALYSIS OF VARIOUS GASES IN DIFFERENT BRITISH TOWNS.

Weight of 100 Cubic Feet at 14·7 lbs. Pressure per Square Inch.		Volume of 1 lb. Weight at 14 lbs. per Square Inch Pressure.		Heat evolved by 1 lb. Weight in British Thermal Units.	Heat evolved by 1 Cubic Foot at 14·7 lbs. pressure.				Volume at 17° C. and 14·7 lbs. per Sq. In. Pressure, which evolves Heat equivalent to 1,980,000 foot-lbs., or 1 H.P. for 1 Hour.
At 0° C.	At 17° C.	At 0° C.	At 17° C.		At 0° C.		At 17° C.		
Lbs.	Lbs.	Cub. ft.	Cub. ft.		B.T.U.	Foot-lbs.	B.T.U.	Foot-lbs.	
4·355	4·100	22·97	24·39	19,827	863	666,560	813	627,740	3·154
3·926	3·691	25·47	27·09	20,604	810	625,960	762	588,530	3·364
4·182	3·937	23·91	25·40	19,600	820	633,030	772	595,890	3·322
3·908	3·679	25·60	27·18	19,551	764	589,770	720	555,490	3·564
3·533	3·326	29·13	30·07	20,471	703	554,268	681	525,720	3·766
3·435	3·234	29·11	30·92	21,375	734	567,040	691	533,830	3·709
3·932	3·702	25·43	27·01	18,786	739	570,490	695	537,110	3·686
3·738	3·519	26·76	28·42	20,520	767	592,150	830	557,570	3·551
3·793	3·571	26·37	28·00	17,645	669	516,730	630	486,650	4·069
3·485	3·281	28·69	30·46	20,945	732	563,750	687	530,640	3·713
3·332	3·137	30·01	31·88	20,666	688	531,770	648	500,580	3·955
2·866	2·700	34·89	37·04	22,912	664	507,110	618	477,680	4·145
3·160	2·975	31·65	33·61	21,906	692	534,480	652	503,320	3·934
3·172	2·986	31·54	33·49	22,282	707	545,560	665	513,790	3·853
3·053	2·874	32·75	34·79	21,494	656	506,810	618	477,090	4·156
3·151	2·966	31·74	33·71	21,548	679	524,250	639	490,361	4·011
2·862	2·694	34·94	37·12	23,432	670	517,890	631	487,480	4·062
2·852	2·431	35·06	41·13	23,369	666	514,730	568	438,760	4·153
3·500	3·294	28·57	30·36	18,963	665	513,530	572	483,250	4·097
2·880	2·711	34·72	36·89	23,782	685	[illegible],040	645	497,820	3·977

CHAPTER XVIII.

THE UTILISATION OF HEAT IN A GAS ENGINE.

CONTENTS.—Gas Power *versus* Steam Power—Balance of Heat—Four Efficiencies—Ideal Diagram—Actual Otto Diagram—Ayrton and Perry's Experiments—Formulæ of Efficiency—Four Types of Engine—Heat Balance Sheet.

HAVING now considered the laws governing heat, the chemical nature of the changes taking place in the charge of gas and air in an engine cylinder, and the heat developed, we come to the question how far this heat is really usefully employed as motive power. Upon this vital point the whole theory and practice of a heat engine rest. The heat supplied is used to drive out a piston, but it can never all be turned into work. The analyses and calculations of the heat of gases in the preceding chapter enable us to determine how much heat goes into a motor cylinder, and we must now try and trace what becomes of it. What is the proportion wasted and utilised? What are the causes of the waste of heat, and consequently of power, and how far can this loss be avoided, in the construction and working of a heat engine?

An erroneous idea is sometimes prevalent that heat is a mysterious attribute imparted to a body, which cannot be measured or accounted for. The heat evolved in a gas by combustion in a cylinder does not disappear in some unknown manner. Either it remains to raise the temperature of the gas, or it is dissipated in one of three different ways. A certain quantity is radiated into the atmosphere through the walls of the cylinder, and into the water jacket. Some is expended in power, according to the law of the mechanical equivalent; and a proportion, varying according to the more or less perfect cycle of the engine, is left at the close of expansion, to be carried off into the atmosphere at the exhaust stroke.

Gas Power as Compared with Steam Power.—It has now been proved by experiment that a good gas engine turns about double as much heat into work as a good steam engine. This is chiefly because the range of working temperatures is very much higher. In a boiler and steam engine the source of heat, the furnace, is separated from the engine, and the steam is raised to its highest temperature before it enters the cylinder. However carefully the steam pipes may be covered, they carry off some

heat. The temperature of the working agent cannot be so great when heat is added externally, before work on the piston is begun, as when it is imparted actually inside the cylinder, as in a gas motor. When the water in a boiler is converted into steam, a change of physical condition takes place. A certain quantity of heat becomes latent, or is stored up without raising the temperature of the steam, in order to produce the change from a liquid to a gaseous state. Nor does steam wholly conform to the law of Gay-Lussac, because it is not a perfect gas. It increases more rapidly in pressure than in temperature, when heat is applied to it. At a temperature of 450° C. absolute, it has a pressure of 10 atmospheres = 150 lbs. to the square inch. From these causes the initial temperature of the steam is relatively low; the range, or difference between the two sources, is never very great, and consequently less heat is available to be utilised in work. The heat efficiency of a well-jacketed modern steam engine may be taken at from 8 to 14 per cent., depending on the speed, pressure, &c.—that is, about one-seventh or one-twelfth of the heat received by the engine is turned into work (exclusive of boiler).

In gas engines the conditions are very different. Combustion generally takes place in the cylinder itself, or in a contiguous chamber, and there is no boiler or its equivalent. The gas is introduced into the cylinder at a comparatively low temperature. The heat is produced at once by explosion and combustion, and utilised on the piston. The theoretical temperature of explosion obtained by calculating the heat of combustion of the chemical constituents of the gas, is estimated at from 2,600° to nearly 4,000° C. To two causes, namely internal combustion, and permanence of physical state in the gas, the greater practical efficiency of a gas engine is chiefly due. As compared with steam, it turns into work about twice as much, or from 15 to 28 per cent. of the total heat supplied to it, according to speed, size of engine, &c. From these figures, however, it must not always be assumed that, in all cases, the power at the end of the crank shaft is obtained more economically, because the mechanical efficiency of the gas engine, or the ratio of brake to indicated horse-power, is generally lower than that of a steam engine. In other words, a gas engine often takes more power to drive itself than a good steam engine.

But there are limits to the heat obtained by internal combustion in a gas engine cylinder. Far more heat is developed than can be utilised, or brought safely into contact with the working parts of the engine. Professor Witz says that the limit of working temperature in a heat engine throughout the stroke, is estimated at about 573° absolute = 300° C. It is true that much higher temperatures are obtained in a gas engine; they cannot indeed be avoided, but neither can they at present

be properly utilised. A temperature of 1,600° C. or 1,873° absolute is taken by the best authorities as an average maximum temperature of explosion, and it is seldom lower than 1,000 C. or 1,273° absolute. Such heat must be instantly counteracted and dispersed, and this is obtained by circulating water in the jacket round the cylinder, and thus lowering the temperature of the gas at explosion and afterwards. If it were not for these practical difficulties, the 20 per cent. actual efficiency mentioned above would be considerably increased. In the formula $\frac{T_1 - T_0}{T_1}$, p. 220, T_1 is the maximum temperature of explosion. Practically about one-third to one-half this heat T_1 is carried off by the action of the walls and water jacket, and much of the remainder escapes with the unburnt gases. The colder walls abstract heat which must be dispersed, but might with great advantage be retained. Their action is necessary, but not perhaps to its full extent, and here is a great opening for future improvement.

Balance of Heat.—A most useful method of studying heat and its utilisation in any engine was first introduced by the late G. A. Hirn. He drew up what he termed a heat balance sheet, showing on one side all the heat given to an engine, and on the other how it was expended. It is now usual, following his method, to make such a heat balance, in calculating the results of an engine. The heat received is put on one side of the account, and that dissipated, measured, and unaccounted for on the other. In a gas engine such a heat account, as shown by actual experiments, is about as follows :—

GAS ENGINE—HEAT BALANCE ACCOUNT (AVERAGE).

Dr. Heat received by the Engine.	Per Cent.	Heat accounted for, &c. *Cr.*	Per Cent.
Heat units (T.U.) received per explosion,	100	In work (T.U.) I.H.P., .	22·32
		Carried off by jacket, .	32·96
		Carried off in exhaust gases, ...	43·29
		Carried off by conduction and radiation and unaccounted for, . .	1·43
Total,	100	Total,	100

Of course, the figures vary much with different engines, but the above may be taken to represent good working conditions. They are from Professor Capper's trial of a 7 nominal H.P. Crossley engine, Appendix, Section B. (See other Heat Balance Acounts on p. 252.)

The actual heat supplied to an engine cannot be accurately calculated, unless the calorific value of the gas is known. This may be determined either by chemical analysis, or by combustion in a calorimeter (see p. 232). The gas varies sometimes from hour to hour in the proportions of its chemical constituents, and its heating value differs in every town. The amount of air used to dilute the charge is also an element of uncertainty in making calculations. The ordinary method is to measure the quantity of gas entering the cylinder by a meter, and to calculate the air consumption from the total volume, but this is an unsatisfactory plan. A certain amount of the products of combustion almost always remain in the cylinder, mixing with the fresh charge, and as the quantity of gas admitted does not vary, they must reduce the proportion of air entering with it. The quantity of air should be actually measured, and this has been done by Dr. Slaby and others. It is not an easy process, but is essential for accurate trials.

Expansion.—The utilisation of heat in a gas engine, and its transformation into work, is mainly obtained during the two processes of expansion and compression. The uses of compression, and the great advantages derived from it, have already been explained. It reduces the original volume of the gases, and increases their power of expansion. But since the temperature obtained by explosion in a gas engine is high, the expansive force of the gases is correspondingly high, and is never completely utilised. The gases are always discharged into the atmosphere at a considerable pressure, which, had it been possible to prolong the stroke indefinitely, might be turned to useful account in doing work upon the piston. It is on account of this high expansive energy of the gases that most modern writers insist upon ignition at the dead point. The whole heat is added, and explosion takes place as far as possible at constant volume, or before the piston has moved, and thus the whole volume of the cylinder is available for the expansion of the gases.

Efficiencies. — Engineers usually employ four kinds of Efficiencies, to represent the utilisation of heat and power in an engine.

I. The first is known as the Maximum Theoretical Efficiency of a perfect engine, and is defined in the preceding chapters. It is expressed by the formula, $\frac{T_1 - T_0}{T_1}$, and shows the working of a perfect engine between these limits of temperature (T_1 and T_0).

II. The second is the Actual Heat Efficiency, or the ratio of the heat turned into work to the total heat received by the engine. The work is often given in I.H.P., but B.H.P. should be added if possible.

III. The third is the ratio between the second (actual heat efficiency) and the first (maximum theoretical efficiency). It represents the maximum proportion of possible heat utilisation actually obtained by the engine.

IV. The fourth is the Mechanical Efficiency. It is the ratio between the useful horse-power (or brake H.P.) available at the end of the crank shaft, and the total indicated horse-power. The difference between the two is the I.H.P. necessary to drive the engine itself. Suppose an engine indicating a total of 100 H.P., and that by a special experiment it was found that 20 H.P. was required to keep the engine going at the same speed, without any external work. In such a case the mechanical efficiency would be 80 per cent. Examples of these important different efficiencies are given in Professor Capper's tests (p. 430), also by Miller "On Efficiencies," and by other writers on the subject.

Ideal Diagram.—The diagrams representing the area of work in a heat engine are similar to that of Carnot's perfect cycle, but vary in shape according to the type of motor, and the curves produced by the pressure, expansion, and cooling of the gases. Fig. 109 represents a perfect cycle, in which the gases are compressed before ignition. The line A B is the abscissa, and is proportionate to the cylinder volume and the length of stroke. The line D F is the ordinate of pressure, and the mean height of the area D F B C D gives the mean pressure. Explosion takes place at D, the pressure rising instantly to F without change of volume, as the piston is stationary. From F to B the charge expands, and all the work of the engine is done. The pressure and temperature fall in consequence. From B to A the gases are discharged at atmospheric pressure. The piston draws in the charge from A to B and compresses it into the clearance space.

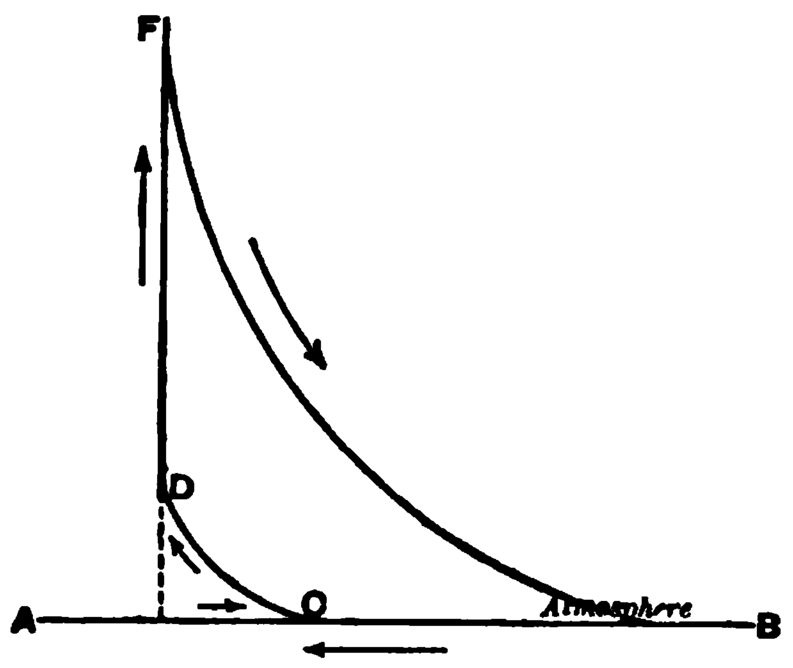


Fig. 109.—Diagram of Perfect Cycle with Compression.

In this ideal diagram all the lines follow Carnot's cycle. Compression and explosion are both adiabatic, that is to say, no heat is lost, but all is transformed into energy, and again refunded by compression of the charge. The gases also expand till their pressure falls to atmospheric, and their whole energy is supposed to be utilised. The diagram is formed of two adiabatic lines, compression and expansion; a vertical explosion

line with no increase in volume during the rise in pressure, and a horizontal exhaust line, with no back pressure during the return to the original volume.

Actual Otto Diagrams.—We will now consider what really takes place in an engine, and the area of work shown by an indicator diagram. Fig. 110 is an actual indicator diagram taken at a trial of an Otto engine by Messrs. Brooks & Steward, and similar to most modern diagrams. Here A B is the line of atmospheric pressure, and almost parallel with it is the line of admission, A C. It will be remembered that, in the Otto cycle, the piston draws in the charge during one entire forward stroke. If the lines A B and A C be compared, the latter will be seen to be rather lower, showing that there is a small vacuum in the cylinder, and the charge is admitted at a pressure slightly below that of the atmosphere. From C to D the charge is compressed, the pressure rises, but the line falls below the adiabatic (compare C D in Fig. 109). Evidently the heat is carried off and abstracted by the cooler walls, as well as stored up by the compression of the gas. From D to F is the explosion line, which also deviates from the perfectly vertical line in Fig. 109. The top of the diagram is rounded, showing that the piston had begun to move a little before explosion was complete; the pressure did not at once attain its maximum, nor was combustion complete when the highest pressure was reached. The line of expansion F G differs from the true theoretical adiabatic curve. Various circumstances, such as "after-combustion," and also the cooling action of the walls, contribute to

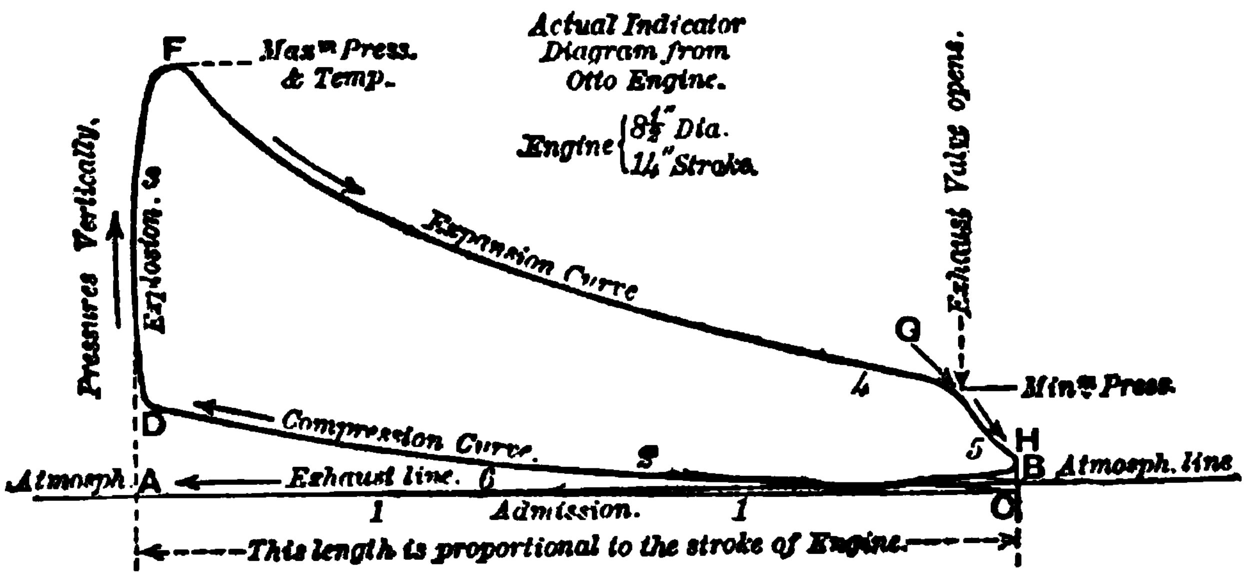


Fig. 110.—Otto Engine—Actual Indicator Diagram—Single Cylinder—Single Acting. (The figures indicate sequence of operations.)

alter the shape of the expansion curve in actual gas engines. At G a phenomenon occurs, with which nothing in Fig. 109 corresponds. The exhaust valve opens prematurely, while the gases are still at a high temperature and tension, and the pressure falls suddenly, before expansion is completed; the gases escape into the atmosphere, instead of continuing to act upon

the piston. At H the end of the stroke is reached, and the gases of combustion are discharged along the return line from H to A. At the beginning of the return stroke this line is above the atmospheric pressure to which the gases are in theory reduced at the end of expansion, and there is a certain amount of back pressure, or pressure retarding the motion of the piston.

This indicator diagram may be taken as a typical representation of the curves of pressure usually obtained in an Otto engine during two revolutions. The chief reasons for the variations in this, as compared with a theoretical, cycle, are:—

1. Explosion is not instantaneous, and continues after the piston has begun to move out.

2. Combustion is not completed till some time after the beginning of the stroke, and the whole heat is not developed instantaneously.

3. Heat is carried off by the walls and the water jacket, to reduce the temperature within practicable limits.

4. Expansion is never adiabatic, and the whole heat expended or evolved from the gas is not absorbed in doing work.

5. Expansion is not continued till the pressure of the gases is reduced to atmospheric, but they are discharged much before their full pressure has been utilised in work on the piston.

Ayrton and Perry.—A very complete and careful study of a 6 H.P. Otto gas engine indicator diagram will be found in a paper by Messrs. Ayrton and Perry, in the *Philosophical Magazine* for July, 1884. The authors consider, first the action in the cylinder and the nature of the working fluid, both before and after combustion; next, the shape of the indicator diagram as regards the compression and expansion of the mixture, and the influence of vibrations in the indicator spring. Formulæ are given for calculating the curves. The heat imparted to the fluid, determined from its volume and pressure, is also studied, as well as the total heat and work during the cycle, and the loss of heat during compression and by radiation.

Formulæ for Efficiencies.—Although the formula $\frac{T_1 - T_0}{T_1}$ applies equally to all heat engines, there are various types of gas motors, each utilising differently the heat supplied. In practice they are classified under four heads. In each of these types the indicator diagram varies slightly in shape, and the actual efficiency may be expressed by a different formula. The formulæ of efficiency now generally used in calculating the work obtained in theory from a gas engine were originally drawn up by Professors Schöttler and Witz, and Mr. Dugald Clerk, from whose able generalisations the following figures are taken:—

The first three types of gas engines are direct acting, and the heat supplied acts directly by expansion of the

gas upon the piston; the fourth is indirect acting, the expansion of the gases forces up the piston, but no work is done except during its descent. The formula for calculating the maximum theoretical efficiency is, as already given, $\frac{T_1 - T_0}{T_1}$, in which T_1 represents the highest absolute temperature attained by the gases, T_0 the temperature (absolute) to which they fall after doing work on the piston, and $1 - \frac{T_1 - T_0}{T_1}$ the percentage of heat utilised. The same formula may be differently stated, thus—

$$\frac{Q}{1 + n} = c_v (T_1 - T_0)$$

or—The total quantity of heat developed by the explosion of the gases (Q) divided by the weight of the charge (1 of gas plus n dilution of air) is equal to the highest absolute temperature of the gases, T_1, less the lowest absolute temperature, T_0, multiplied by their specific heat at constant volume, c_v. The specific heat of the gases at constant volume is taken, because it is assumed that the whole of the heat is added before the piston has moved. From the quantities of heat the pressures can be deduced, according to Boyle's law. Thus $p_1 = p_0 \frac{T_1}{T_0}$ or—The highest pressure, p_1, developed by the explosion of the gases is equal to the initial pressure, p_0, multiplied by the ratio between the highest and lowest absolute temperatures. In the following formulæ the pressures are omitted, but they can be worked out by the student from the temperatures.

1. **The first type** of gas motor is the direct-acting non-compression engine. Here the gases are not compressed before ignition, but are admitted into the cylinder at atmospheric pressure and ordinary temperature. All the heat is then generated at once, and the gases expand, driving the piston to the end of the stroke. The best example of this sequence of operations is furnished by the original Lenoir engine (see diagram, p. 35). In its cycle there are three important temperatures—T_0 the initial temperature of the gases admitted into the cylinder, T_1 the highest temperature during explosion, and T_2 the temperature of the gases at release, after they have done work on the piston. In theory T_2 should be equal to T_0—that is, the gases should be reduced to their original atmospheric temperature. In practice this is never possible, but they are always discharged at a higher temperature than T_0. Q represents the quantity of heat added from the source of heat (in heat units or calories), Q_e the quantity discharged to the exhaust, Q_c the quantity turned into work, and γ the ratio between the specific

heat of the gases at constant volume (c_v) and at constant pressure (c_p). Thus—

$$Q = c_v (T_1 - T_0).$$

The formula for actual efficiency E of this class of engine is:—

$$E = \frac{c_v (T_1 - T_0) - c_p (T_2 - T_0)}{c_v (T_1 - T_0)} = 1 - \gamma \left(\frac{T_2 - T_0}{T_1 - T_0}\right) = 1 - \frac{Q_e}{Q}$$
$$Q_e = Q - Q_w.$$

2. In the **second type** of engine the gases are compressed before ignition, and explosion takes place at constant volume. To the three temperatures given above, and always to be taken into account in estimating the heat efficiency of any engine, the compression of the gases before ignition adds a fourth, T_3 = temperature of compression. Work being done on the gas by driving the particles closer together, heat must be developed. This rise in temperature is calculated by multiplying the original temperature, T_0, by the difference in the volume of the gases before and after compression, raised to the power of the ratio of the specific heats minus 1. The temperatures are here obtained from the volumes, according to Boyle's law. The formula for calculating this temperature of compression is—

$$T_3 = T_0 \left(\frac{v_0}{v_1}\right)^{1{\cdot}408 - 1 = {\cdot}408},$$

where v_0 is volume before compression, v_1 is volume after compression. The Otto four-cycle engine is the best example of this type (see diagram, pp. 92, 93). Thus—

$$Q = c_v (T_1 - T_3) \qquad Q_w = c_p (T_2 - T_0) \qquad Q_e = Q - Q_w.$$

The actual efficiency of this type is—

$$E = \frac{c_v (T_1 - T_3) - c_p (T_2 - T_0)}{c_v (T_1 - T_3)} = 1 - \gamma \left(\frac{T_2 - T_0}{T_1 - T_3}\right) = 1 - \frac{Q_e}{Q}.$$

3. The **third type** represents an engine in which the gases are compressed before ignition, as in the second type, but instead of exploding, they burn at constant pressure. They enter the cylinder as flame, and drive the piston forward, not by the force of the explosion, as in the two former types, but by the expansion of the burning gases. It seems at first as though this type ought, in accordance with the theories hitherto laid down, to give a very low efficiency—that is, to utilise a very small proportion of the heat supplied to it, because there is a constant temperature of combustion during the forward stroke, instead of an instantaneous temperature of explosion. The highest temperature attained is not very great, and there is less range than in the other types. It is, however, an engine giving excellent

results in theory, and it is difficult to understand why these results are not realised in practice. The working defects are attributed chiefly to insufficient compression. The efficiency depends, not on the highest temperature attained, but upon the amount of compression, and the greater the compression the greater the heat. In this class of engine, therefore, the usual rule is reversed, and an efficient cycle is obtained with a low temperature of explosion, T_1. The best example of this type is the Simon engine (see p. 53). In the formula the ratio of specific heat does not appear, because the burning gases are at a uniform temperature throughout the stroke, and all the operations are effected at constant pressure.

$$Q = c_p (T_1 - T_3) \qquad Q_e = c_p (T_2 - T_0) \qquad Q_c = Q - Q_e.$$

$$\text{Efficiency } E = \frac{c_p (T_1 - T_3) - c_p (T_2 - T_0)}{c_p (T_1 - T_3)} = 1 - \left(\frac{T_2 - T_0}{T_1 - T_3}\right) = E = \frac{Q_c}{Q}.$$

4. **Atmospheric Gas Engines.**—To this class belong engines in which the action of the gas upon the piston is indirect, and work is obtained, not by expansion, but by the formation of a vacuum under the piston. Theoretically, this type is the most perfect of all, because of the high explosion pressure, and the apparently unlimited expansion, but this great expansion can never be utilised in practice. A piston of undefined length, permitting the gases to expand until their pressure falls to atmosphere, would be necessary to utilise fully the power developed, and this is impossible under working conditions. As the gases are not previously compressed, there is no temperature of compression, but another temperature must be reckoned, T_4, representing the temperature of the gases after the exhaust has opened, but before they are compressed by the atmosphere, and restored to their original condition. The heat quantities are represented by—

$$Q = c_v (T_1 - T_0) \qquad Q_e = c_v (T_2 - T_4) \qquad Q_c = Q - Q_e.$$

$$\text{Efficiency } E = 1 - \left(\frac{T_2 - T_4}{T_1 - T_0}\right) = \frac{Q_c}{Q}.$$

These formulæ will be best understood, if calculated and expressed in figures. The temperature of explosion in most gas engines is usually taken at from 1000° C. = 1273° Abs. to 1600° C. = 1873° Abs. The initial temperature is commonly assumed to be from about 12° C. = 285° Abs. to 18° C. = 291° Abs. The initial atmospheric pressure is taken at 14·7 lbs. per square inch; the volume of the cylinder is reckoned in cubic feet or cubic metres. In an experiment made on a 4 H.P. Otto engine by Dr. Slaby, the absolute temperatures were computed as follows:—

Initial temperature, ...	T_0, 400° C.
Temperature of explosion, ...	T_1, 1504° C.
Temperature at the opening of exhaust, .	T_2, 1068° C.
Temperature of compression, . . .	T_3, 400° C.

The actual efficiency calculated numerically (see formula of the second type) is—

$$E = \frac{0{\cdot}192\ (1504° - 400°) - 0{\cdot}264\ (1068° - 400°)}{0{\cdot}192\ (1504° - 400°)} = 1 - 1{\cdot}375\ \left(\frac{1068° - 400°}{1504° - 400°}\right)$$

or

$$E = \frac{211{\cdot}96 - 176{\cdot}35}{211{\cdot}96} = 0{\cdot}168 = 1 - 1{\cdot}375 \times {\cdot}605 = 17 \text{ per cent.}$$

From the above formulæ of efficiencies it is evident that, in order to obtain a sufficient fall in temperature, it is of great importance to keep the initial temperature of the gases low. In theory the efficiency of the engine depends on the range of temperature, and the lower the initial temperature, and the higher it can be raised by explosion the better. Much stress is therefore laid by all authorities upon introducing the gases into the cylinder at as low a temperature as possible. The utilisation of the heat in theory depends on the difference between the maximum temperature and the temperature of admission. In practice, however, the hotter the gases (after explosion), the greater will be the difference in temperature between them and the cylinder walls; consequently the waste will also be greater, because they will part with more heat to the water jacket. To obtain an economical working cycle, all losses of heat should be reduced as much as possible. These are, the exposure of a large area of cylinder surface to the hot gases, and length of time during which the exposure lasts. The causes to which waste of heat are attributed will be studied in the next chapter.

The following table gives the heat balance of four different English engines, showing the quantity of heat developed, and the proportions of waste, and of useful work obtained. It is taken from Professor Kennedy's Trial of a Beck engine, and the Trials of the Society of Arts, 1888.

	Beck.	Griffin.	Atkinson.	Otto-Crossley.
Heat developed per explosion,	19,980 ft.-lbs. 100 %	20,650 ft.-lbs. 100 %	13,280 ft.-lbs. 100 %	34,040 ft.-lbs. 100 %
,, converted into work,*	3,870 ,, ,, 19·4 %	4,350 ,, ,, 21·1 %	3,390 ,, ,, 25·5 %	7,515 ,, ,, 22·1 %
,, carried off in cooling jacket water,	6,610 ,, ,, 33·0 %	7,260 ,, ,, 35·2 %	3,590 ,, ,, 27·0 %	14,700 ,, ,, 43·2 %
,, carried off at exhaust,	8,570 ,, ,, 42·9 %	8,220 ,, ,, 39·8 %	5,030 ,, ,, 37·9 %	12,100 ,, ,, 35·5 %
,, unaccounted for,	930 ,, ,, 4·7 %	820 ,, ,, 3·9 %	1,270 ,, ,, 9·6 %	·8% over balance
Diameter of cylinder,	7·5 inches.	9·02 inches.	9·5 inches.	9·5 inches.
Stroke,	15 ,,	14 ,,	12·43 ,,	18 ,,
Number of revolutions,	206·5	198	131	160
Indicated horse-power,	8·05	15·47	11·15	17·12
Brake horse-power,	6·31	12·51	9·48	14·74
Mechanical efficiency,	87 per cent.	85 per cent.	85 per cent.	86 per cent.

* Taking I.H.P. for the work.

CHAPTER XIX.

EXPLOSION AND COMBUSTION IN A GAS ENGINE.

CONTENTS.—Definition of Terms—Rate of Inflammability in Gases—Bunsen, Millard and Le Chatelier, Berthelot and Vieille, Witz, Clerk, Grover, Burstall—Wall Action—Equilibrium of Heat—Stratification—Clerk's Experiments on a Crossley-Atkinson Engine—Dissociation—Wall Cooling—Increase of Specific Heat—Cylinder Wall Action.

THE phenomena taking place and work obtained in a heat engine have now been shown to depend on the development and utilisation of heat. Since heat in the cylinder is obtained by the ignition, explosion, and combustion of a certain quantity of air and gas, the character of these phenomena, the strength of the explosion, and speed of propagation of the heat through the gas, are of the utmost importance. For many years they have engaged the attention of scientific men. By careful study and observation, a sufficient number of exact experimental facts have been accumulated to determine with precision the action of gas in an engine cylinder.

Definition of Terms.—Before proceeding to consider these phenomena, it will be well to define the different expressions generally used. Four terms are employed to denote the effects produced by heat in the cylinder of a gas engine—1, Ignition; 2, explosion; 3, inflammation; 4, combustion. Ignition takes place when sufficient heat is communicated by a flame, electric spark, or hot tube, to the gaseous mixture to fire it. Inflammation is the subsequent spreading of the flame throughout the gas, or its propagation from one particle to another, till the whole volume is alight. Explosion follows when the mixture is completely inflamed, and the maximum pressure attained. When all the gas in a cylinder is thoroughly alight, the particles are driven widely apart, and thus the moment of complete inflammation will also be that of maximum pressure. Complete inflammation and explosion are thus practically simultaneous. Combustion is complete when all the chemical changes have taken place, and the gases have been reconstituted as water vapour (H_2O) and carbonic acid gas (CO_2). This moment may not coincide in point of time with explosion. The chemical recombination of the gases, and consequently the evolution of all the heat contained, is almost always delayed in a gas engine until an appreciable time, or fraction of a second, after the maximum pressure is developed, and the piston has begun to move out, as shown by the indicator diagram.

Velocity of Flame Propagation—Bunsen.—It is at the

moment when explosion occurs that the maximum pressure is reached, and probably also the maximum temperature.* The importance of this temperature has been proved theoretically in the preceding chapter, and many experiments have been made to determine it, because it marks the rate of inflammation, or of propagation of the flame. The celebrated chemist, Bunsen, was the first to calculate the rate of flame propagation—or of inflammability—in a gas. He confined the mixture in a vessel having a very small orifice, and the gas was ignited as it passed out. The mouth of the orifice was reduced till the pressure of the issuing flame was exactly equal to that of the gas inside, and as soon as the balance of pressure was established, the flame spread back till it had ignited the gas in the vessel. The method of ignition used in the Koerting engine is somewhat similar. The rate at which the gas issued from the vessel being known, the speed of the flame, as propagated back through the mixture, was calculated from it. By these means Bunsen determined the velocity of propagation, or the inflammability of a gaseous flame. With a mixture of 2 volumes hydrogen and 1 volume oxygen, he found it to be 34 metres = 111·5 feet per second; with carbonic oxide it was 1 metre = 3·28 feet per second.

Mallard and Le Chatelier.—Later researches have shown that these figures are not accurate. The instrument then used could not be wholly relied on, because the external air cooled the flame as it issued from the orifice, and affected the results. A series of elaborate experiments have been conducted by MM. Mallard and Le Chatelier with a long tube filled with an explosive mixture, closed at one end, and communicating through the other with the open air. The period of explosion, or the time occupied by the flame in travelling through the tube, was marked by revolving drums and tuning forks, the latter being the best instruments for measuring, by their vibrations, fractions of a second. The drums revolved on the same shaft, close to either end of the tube, and a wavy line was traced upon them by the vibrations of the tuning forks, set in motion by the explosion. As soon as the gas at one end of the tube was ignited, it moved a small pencil, and marked the drum revolving at that end. A second pencil made a similar mark on the drum at the other end, when the flame had passed through the length of the tube. The distance between the two marks, measured on the vibrating line traced by the tuning forks, gave the time of propagation of the flame. With the same mixture of hydrogen and oxygen as that used by Bunsen, Mallard and Le Chatelier found the velocity to be 20 metres = 65·6 feet per second, and with

* Dr. Slaby says that "combustion is completely ended after a fractional portion of the stroke, from 0·03 to 0·06 of a second."—*Calorimetrische Untersuchungen*, p. 161.

carbonic oxide 2·2 metres = 7·2 feet per second, or a speed double that given by Bunsen.

These pure explosive mixtures are too strong to be used in a gas engine, as air is necessary to dilute the gas, and the mixture becomes immediately weakened with a large proportion of non-explosive nitrogen. MM. Mallard and Le Chatelier, therefore, varied the strength of the mixture. With 1 vol. hydrogen mixture (*i.e.*, 2 vols. hydrogen to 1 of oxygen) and 1 vol. oxygen, the rate of flame propagation was 10 metres = 32·8 feet per second. The highest velocity was found to be the mixture of 1 vol. hydrogen to 1 vol. oxygen, originally used by Bunsen, but to obtain a standard for the dilution commonly employed in a gas engine, the experimenters combined hydrogen with air in the proportion of 2 vols. hydrogen to 5 of air. The following table (from Clerk) shows the velocity of flame with hydrogen and various volumes of air :—

TABLE OF VELOCITY IN DILUTED MIXTURES (*Mallard and Le Chatelier*).

	Velocity per second.	Velocity per Second.
Mixture of 1 vol. hydrogen and 4 vols. air	2 metres.	6·5 feet.
,, ,, ,, ,, 3 ,,	2·8 ,,	9·1 ,,
,, ,, ,, ,, $2\frac{1}{3}$,,	3·4 ,,	11·1 ,,
,, ,, ,, ,, $1\frac{6}{7}$,,	4·1 ,,	13·4 ,,
,, ,, ,, ,, $1\frac{1}{2}$,,	4·4 ,, *max.*	14·4 ,, *max.*
,, ,, ,, ,, 1 ,,	3·8 ,,	12·4 ,,
,, ,, ,, ,, $\frac{1}{3}$,,	2·3 ,,	7·5 ,,

In these experiments the explosive mixtures were at constant pressure; the end of the tube being open, the ignited gases issued from it in a continuous stream, and did external work against the pressure of the atmosphere. When both ends of the tube were closed, and the mixture was ignited at constant volume, the velocity with which the flame was propagated was very much greater. A speed of 1,000 metres = 3,280 feet per second, instead of 20 metres, was verified with hydrogen explosive mixture (2 vols. H and 1 vol. O). When the hydrogen was diluted with air, the speed was 300 metres = 984 feet per second. This great difference in the rate of flame propagation is attributed by MM. Mallard and Le Chatelier to inflammation taking place, not only by the projection of the flame from one particle to another, but by the expansion of the particles through the heat generated. As they ignite, they rise in temperature and pressure, and the propagation of the flame is thus assisted. When the mouth of the tube is closed, and the particles cannot expand freely into the atmosphere, the

ignited portions of the gas are forcibly projected into the parts not yet kindled. These experiments prove the greatly increased velocity of flame propagation when the volume of the gases is constant, and therefore the value of ignition at the dead point in a gas engine. The maximum explosive pressure is higher and more rapidly obtained, when the piston is stationary.

Berthelot and Vieille.—A series of valuable experiments were also carried out by MM. Berthelot and Vieille, to determine the rate of flame propagation (or of complete combustion, since in this case the two terms are synonymous) of gases at constant volume in a closed vessel. The time of explosion was determined in receivers of three different capacities—namely, 300, 1500, and 4,000 cubic centimetres. Two of the vessels were cylindrical and the third spherical, and each was fitted with a registering piston. At either end they terminated in a short tube; at the further end of one an electric spark was produced for firing the mixture, the other contained the piston. The lengths of the igniting tube, the cylinder, and the tube containing the piston being known, the time occupied by the flame in passing through the gas, from the point of ignition till the explosion reached and forced up the piston, could be calculated. The experiments were made with a variety of chemical compounds, such as bioxide of nitrogen, cyanogen, and compounds of hydrogen, oxygen, carbon, and nitrogen. The larger the capacity of the vessel or receiver, the longer time was found to elapse, with every mixture, between the ignition of the gas, and the attainment of maximum pressure. This agrees with Gay Lussac's law, since the smaller the vessel and the volume of the gas, the greater will be the increase in pressure produced by the high temperature of ignition. The effect of the composition of the mixture, and of the more or less perfect combustion obtained by adding oxygen in exact proportion or in excess, were also noted.

But one of the most important practical results of these experiments, with regard to the phenomena in a gas engine, was obtained with the products of combustion. By using a mixture of the chemical elements contained in these products, and observing the time occupied by the projection of the flame, MM. Berthelot and Vieille proved that the rate of flame propagation in such compounds was slower than with pure mixtures, representing the fresh charge of gas and air in a cylinder. Dilution with the products of exhaust, therefore, whether advantageous or not, must retard the rate of combustion, because these products contain an excess of some of the gases. With gases not perfectly combined, and where combustion is incomplete, the rate of flame propagation was found to be most rapid, perhaps because partial dissociation takes place and retards total combustion. MM. Berthelot and Vieille are of opinion that, by the ignition of the gas and the high temperature produced in the closed

vessel, what they term an "explosive wave" is formed, the velocity of which is greatly in excess of the ordinary velocity of flame propagation. They call it the rate of detonation. The explosive wave is generated by the shock of igniting a large portion of the inflammable gas at once; the flame is propagated with a velocity due to the shock, almost as great as the velocity of combustion. For hydrogen the velocity of this explosive wave is 2,810 metres = 9,216 feet per second; for carbonic oxide it is 1,689 metres = 5,539 feet per second.

Regarding the time of attainment of maximum pressure during explosion at constant volume, they say:—"The variations in this time are very important. The maximum pressure observed in a vessel of any given capacity is always less than the pressure which would be developed, if the system retained all the heat due to chemical reaction, for there is always a certain loss from contact with the walls and radiation. The smaller the quantity of gas in proportion to the vessel containing it, and the more slowly combustion takes place, the greater is this difference. The time occupied by combustion varies much; it corresponds to the different conditions developed at the beginning of the phenomena, and is intermediate between the velocity of the explosive wave, and the ordinary velocity of flame propagation of any given gas."

Witz.—Valuable as these theoretical determinations are in studying the theory of combustion, practical experiments are needed to calculate the actual result of generating heat in a gas, by combustion in an engine cylinder. With this object, Professor Witz undertook a number of valuable experiments to illustrate the action of ordinary lighting gas, when mixed with various proportions of air, and ignited. He also desired to show the influence of nitrogen in affecting injuriously the true rate of flame propagation. In MM. Berthelot and Vieille's experiments, the gas was always at constant volume, and no expansion was possible. M. Witz used an ordinary cylinder and piston, and the charge was allowed to expand freely. The first tests were made, not with lighting gas, which varied too much in composition to give accurate results, but with a mixture of carbonic oxide and air; the calorific value at given temperatures of each chemical element was previously determined. A basis being thus obtained for exact computation, lighting gas was used for the rest of the trials, and the differences in chemical composition neglected. Professor Witz attached a tuning fork to the indicator diagram, in order to measure, not only the pressure developed by the explosion, but the fractions of a second before the maximum pressure was attained. Taking the ratio of this time to the length of stroke of the piston, he reckoned the speed of expansion thus—

$$\frac{\text{Length of stroke in feet}}{\text{Duration of explosion in seconds}} = \text{speed of expansion in feet per second.}$$

Calculating the work done from the area of the diagrams, and its ratio to the theoretical work obtained from the number of calories in a given volume of gas and air, Professor Witz found that the percentage of work actually done increased in proportion to the speed of expansion. Some of the results of his able experiments made with lighting gas mixed with varying proportions of air, are summed up in the following table :—

EXPERIMENTS OF PROFESSOR WITZ ON TOWN GAS, WITH CONSTANT MIXTURE OF 1 VOLUME GAS TO 9·4 VOLUMES AIR.

[Vol. of mixture, 2·081 litres.]

Duration of Explosion in Fractions of a Second, taken from Diagrams. *a*.	Length of Stroke of Piston. *b*.	Speed, Metres per Second. $\frac{b}{a} = c$	Theoretical Work. *d*.	Work calculated from the Diagrams. *e*.	Utilisation or Per Cent. of Work done, Ratio of columns *d* and *e*. $\frac{e}{d}$
Second.	Millimetres.	Metres.	Killogram-metres.*	Killogram-metres.	Per Cent.
0·48	122	0·25	446	5·3	1·2
0·47	127	0·27	446	5·3	1·2
0·40	127	0·32	446	7·0	1·5
0·39	132	0·34	446	6·6	1·4
0·31	140	0·45	446	7·8	1·7
0·23	147	0·64	446	10·8	2·4

[1 Litre = 61·025 cub. ins.]

MIXTURE OF 1 VOLUME GAS TO 6·33 VOLUMES AIR.

[Vol. of mixture, 2·081 litres.]

0·15	259	1·7	633	17·6	2·7
0·09	259	2·9	633	40·1	6·2
0·06	259	4·3	633	50·5	7·9
0·06	259	4·8	633	50·7	9·3

In both these series of experiments the volume of the charge was the same—namely, 2·081 litres = 0·73 cubic foot. The richness of the mixture, the length of stroke, and the duration of the explosion varied. Fig. 111 shows a diagram of the expansion, with the vibrations below of the tuning fork used as a measure of time. Each vibration corresponds to $\frac{1}{128}$ of a second. The diagram gives the pressures and volumes, the lower waves mark the time occupied in expansion. The atmospheric line, H*x*, shows that expansion was continued to below atmospheric pressure. From these and many similar experiments, Professor Witz has formulated the two following laws concerning the expansion of gases :—

* One kilogrammetre is one kilogramme × one metre = 2·20 lbs. × 3·28 ft. or 7·2 ft.-lbs. of work done per second (see p. 215).

I. The utilisation of the heat supplied to the engine increases with the speed of expansion.

II. The greater the speed of expansion, the more rapid will be the combustion of the explosive mixtures.

This speed of expansion, which the above table shows to have so important an effect on the proportion of actual to theoretical work, Professor Witz considers to be only the expression under another form of the great influence of the walls, and their cooling action upon the hot gases. "The maximum explosive pressure," he says, "depends on the ratio of the cooling surface of the receiver (or cylinder) to the volume of the gas." In his opinion, nearly all the differences between the action of the gases, in theory and in practice, in the cylinder of an engine, which have hitherto been so difficult to account for, may be attributed to the effect of the walls.

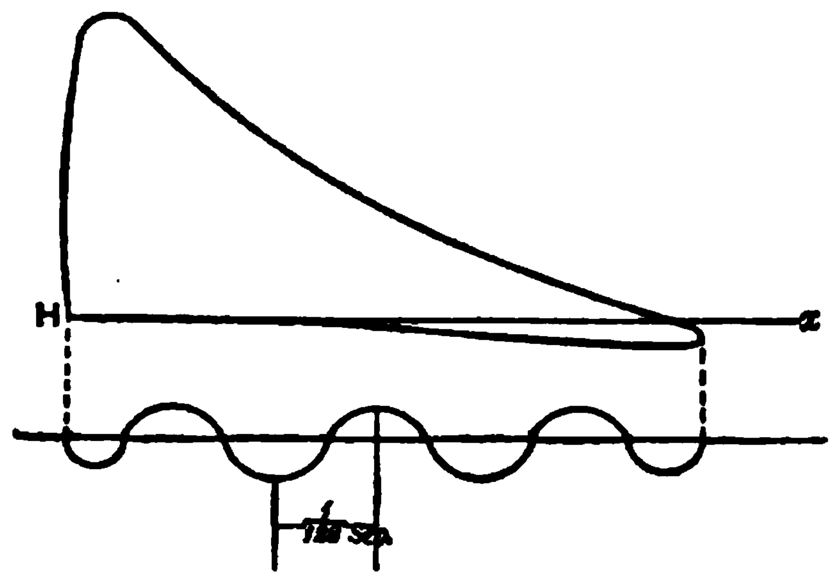


Fig. 111.—Witz' Time Diagram.

Clerk.—Mr. Dugald Clerk was led by his experiments to almost the same conclusions as Professor Witz, though he approached the subject from another point of view. He considered that, to understand the action of gas in a cylinder, it was necessary to determine not only its rate of explosion, that is, the time required to attain maximum pressure, but also the duration of this pressure. It is the force of the explosion which produces effective pressure on a piston. It seems therefore as if, the stronger the mixture employed within working limits, the more useful will be the effect, but experiments have shown this view to be erroneous. The greater amount of work is obtained, not from the most explosive mixture, but from that giving the maximum pressure in proportion to the surfaces, and maintaining that pressure during the longest period of the stroke. Since radiation cannot be prevented, the higher the explosive pressure and temperature generated, the more rapidly will the heat be carried off by the walls of the cylinder, and the pressure correspondingly reduced. This is one reason for the difference between theory and practice in an engine cylinder. Theoretically the highest explosive pressures are the best; but in practical working they are not found the most effective for power.

Mr. Clerk's experiments were made with a small cylinder without a piston, filled with different explosive mixtures, to which an indicator was connected. The indicator drum and paper were made to revolve so that each tenth of a revolution occupied

0·033 second. The pressure of the explosive gases forced up the indicator pencil, causing it to trace different curves on the moving drum. By dividing the area of the drum into sections, the time occupied by the explosion, and cooling or reduction of pressure of the gases, could be estimated within $\frac{1}{100}$ of a second. On this diagram the ordinates represented pressures, as usual, and the abscissæ the time of explosion in fractions of a second. The conditions under which gases explode in the cylinder of an engine were reproduced in all but two respects. Under ordinary circumstances the piston in a gas engine uncovers during the stroke fresh portions of the cooler walls to the hot gases, and the explosive pressure is rapidly lowered. Here the maximum explosive pressure was developed in a closed vessel, and, therefore, at constant volume; and the cylinder having no piston, no heat was expended in doing work. The conditions were similar to those of an engine before the piston has moved.

Mr. Clerk gives several diagrams showing that the pressures of the gases fell much more slowly than they rose. The maximum pressure was produced in 0·026 second after ignition; the fall to atmospheric pressure and temperature occupied 1·5 second, or nearly sixty times as long. Without previous compression of the gases, the highest pressure obtainable with a dilution of 1 part gas to 5 parts air (that is, the mixture containing just enough oxygen to produce combustion of the gas) was only 96 lbs. per square inch. With compression and a much weaker mixture, this pressure was nearly doubled. Mr. Clerk proved that the "critical mixture," or the weakest dilution of gas and air that will ignite, varied according to the quality of the gas used. With Oldham gas a charge of 1 part gas to 15 of air ignited, and the pressure produced was 40 lbs. per square inch above atmosphere. With Glasgow gas the critical mixture was 14 of air to 1 of gas, and the pressure produced was 52 lbs. per square inch.

To determine the best and most serviceable mixture for use in a non-compressing gas engine, the following calculations were made. Mr. Clerk supposed 1 cubic inch of gas to be diluted with air in the ratio of 13, 11, 9, 7, and 5 cubic inches, and these mixtures to be admitted into cylinders having pistons, the areas of which per square inch were in proportion to the strength of the dilution. Thus the charge of 14 cubic inches—viz., 1 volume gas to 13 volumes air—would be admitted into the cylinder having a piston surface of 14 square inches. The mixture of 6 cubic inches would be contained in the cylinder having a square piston area of 6 inches, and the depth of the mixture in the cylinder would always be 1 inch. The maximum pressure of these mixtures he had already determined, as well as their time of explosion, by the instrument mentioned as shown in the following table:—

EXPERIMENTS BY MR. CLERK ON EXPLOSION AT CONSTANT VOLUME IN A CLOSED VESSEL WITHOUT PISTON. MIXTURES OF AIR AND GLASGOW COAL GAS.

Mixtures used. Gas.	Air.	Maximum Pressure above Atmosphere in lbs. per sq. inch.	Time of Explosion, or time elapsing between Ignition and Maximum Pressure.
1 volume plus	13 volumes, .	52 lbs.	0·28 second.
1 ,, ,,	11 ,, .	63 ,,	0·18 ,,
1 ,, ,,	9 ,, .	69 ,,	0·13 ,,
1 ,, ,,	7 ,, .	89 ,,	0·07 ,,
1 ,, ,,	5 ,, .	96 ,,	0·05 ,,

Temperature before explosion, 18° C. = 291° Abs. Pressure before explosion, atmospheric.

By these and other experiments Mr. Clerk found that the highest pressures, giving respectively 756 lbs. and 728 lbs. upon the total piston area, were obtained with a dilution of 11 and 13 volumes of air to 1 of gas. The stronger mixtures gave lower pressures, because, being contained in smaller cylinders, the pressure, to a uniform depth of 1 inch, was exerted over a smaller piston surface. The rate of cooling, or of fall in pressure, was calculated in the same way. Taking one-fifth of a second as the mean time occupied by the piston in making its forward stroke, the pressure of each gas when that time had elapsed, after the attainment of maximum pressure, was computed from the indicator diagram. Multiplying this pressure by the piston area, it was found that the weakest mixtures gave the highest relative pressure at this point in the stroke, showing that these weak mixtures maintained their pressure longest. The following table exhibits the results for five different dilutions:—

EXPERIMENTS BY MR. CLERK ON MIXTURES OF AIR AND GLASGOW GAS AT CONSTANT VOLUME (*with same Apparatus*).

Mixture.	Pressure produced on piston by 1 cub. in. gas.	Pressure in lbs. per sq. in., 0·20 second after max. press.	Pressure remaining upon piston area 0·20 sec. after max. pressure.	Mean Pressure.
1 vol. gas plus 13 vols. air	728 lbs.	43 lbs.	602 lbs.	665 lbs.
1 ,, ,, 11 ,,	756 ,,	48 ,,	576 ,,	666 ,,
1 ,, ,, 9 ,,	690 ,,	47 ,,	470 ,,	580 ,,
1 ,, ,, 7 ,,	712 ,,	55 ,,	440 ,,	576 ,,
1 ,, ,, 5 ,,	576 ,,	57 ,,	342 ,,	459 ,,

Mr. Clerk also made experiments with pure hydrogen diluted with air, but found the pressures much lower than with gas.

The best mixture, 1 volume hydrogen to 5 volumes air, gave a mean pressure of only 267 lbs. upon a piston of proportionate area, one-fifth of a second after explosion. For further details of these interesting experiments, the student is referred to Mr. Clerk's excellent book *The Gas Engine*, pp. 95 to 104.

Another interesting series of experiments were carried out at Yorkshire College, Leeds, in 1895, by Mr. Grover,* upon the pressures obtained with explosive mixtures of coal gas and air, when diluted with the products of former combustion. These tests seem to prove that with a certain proportion of fresh air admitted, the products raise instead of lowering the maximum pressure. The apparatus used was a closed vertical cast-iron cylinder without piston, of constant volume, and 1 cubic foot capacity. The charge was fired electrically, the temperatures were taken by a thermometer, and the pressures recorded by a Crosby indicator with continuously revolving drum, driven by clock work. The time was marked by a vibrating spring producing a wave every eighth of a second. A certain proportion of the previous charge being retained, half the volume of air required for dilution was then introduced, next the charge of gas, and lastly, the remainder of the air. The author considers that, in a gas engine cylinder, the gas and air are more perfectly mixed with each other than with the residual charge. With 58 per cent. by volume of the products left in the cylinder, he found that the limit of inflammability was reached, and no ignition could be obtained. He was also of opinion that it is the ratio of air to gas alone which determines the force of the explosion, and he confirmed Mr. Clerk's experiments that, when this ratio is less than 5·7, the charge will not ignite.

The pressures recorded were lower than those obtained by Mr. Clerk, and accounted for only 41·5 per cent. of the total heat, but this is attributed to the water present in the cylinder, which took up heat by its evaporation. The different data obtained are carefully plotted in curves and diagrams, and from them the author deduces the following important conclusions:—That the highest pressures are obtained when the volume of fresh air admitted is only a little more than that required for complete combustion; that this proportion should never be more than 5½ times that of the gas, but if this ratio is preserved the charge may be diluted up to 58 per cent. with the products of combustion; that the latter should always take the place of an excess of air, not of the air required for diluting the gas; and when they thus replace an excess of air the time of explosion is much reduced.

* See his paper on "The Effects of the Products of Combustion upon Explosive Mixtures of Coal Gas and Air," reprinted from *The Practical Engineer*, 1895.

Experiments were also made in 1895 at King's College, London, by Mr. F. W. Burstall, on the measurement of the temperature in the cylinder of a gas engine during the explosion stroke. It had previously been found impossible to determine these very high temperatures, owing to their rapid variations, and the high pressures developed. After many trials Mr. Burstall succeeded by means of a modified form of Callendar's electrical thermometer, consisting of a naked platinum wire, 0·0025 inch diameter and ¾ inch in length. A small thermal capacity was essential, as during one stroke, occupying less than one quarter of a second, the temperature varies 500° C.

The wire was introduced into the cylinder by means of a steel tube, through which leads passed to the measuring instruments. The changes of electrical resistance produced by changes of temperature in the wire were measured by means of a Wheatstone bridge and mirror galvanometer. The thermometer was calibrated by determining its resistance in ice, steam, and sulphur vapour, an important point. By special means the galvanometer circuit was closed at any particular point of the explosion stroke. The electrical resistance of the wire at that part having been determined, the corresponding temperature was deduced. In the original paper in the *Philosophical Magazine* for September, 1895, the temperature results are plotted, and may be summarised as follows:—In a 7 H.P. single cylinder Otto-Crossley engine, of 8½ inches cylinder diameter and 18-inch stroke, working at 120 revolutions and 13 explosions per minute, the temperature in the centre of the clearance space varied during the motor stroke from 1,200° C. at 10 per cent., to 850° C. at 80 per cent. of the stroke.

A Committee has been recently appointed by the Institution of Mechanical Engineers, London, to continue these important experiments on a gas engine specially made for the purpose. It is also intended to determine the effects of variation in the speed of the engine, the ratio of air to gas, the temperature of the cylinder walls, analysis of the gases, and other important points in a gas engine cycle.

Wall Action in Gas Engine Cylinders.—All these researches tend to show that the causes of loss of heat, and consequent waste of heat energy, depend largely upon the total internal area of the cylinder exposed to the gaseous mixture. The less this area for a given cylinder volume, the higher will be the pressure. Therefore, the more the action of the walls can be diminished during the development of the heat, the more certain and rapid will be the explosion, and the greater the pressure of the gas. This result can be obtained in three ways, by reducing—

1. The time during which the wall action continues.
2. Its intensity.
3. The proportion of area of the walls to the volume of the gases.

1. Opinions vary greatly as to the advantage of high piston speeds in gas engines, but the tendency of modern engineers is, in the main, to increase speed within reasonable limits. Beyond about 300 revolutions per minute, M. Richard considers that the friction and heat developed are too great to work an engine continuously, and if much heat is generated by explosion, a correspondingly large amount is discharged at exhaust. Within certain limits, however, high speeds are advantageous, because the colder walls have less time to act upon the hotter gases, and carry off their heat. The same arguments show the value of ignition at the dead point. The piston having reached the end of its return stroke, and exhausted some of its energy of motion, does not move at the required velocity until driven out again. Explosion being practically completed before the volume of the cylinder is enlarged by the out stroke of the piston, the cooler walls have not much time to diminish the high temperature of the gases produced by explosion, and reduce the pressure before it can act on the piston. The rapid expansion so much insisted on by Professor Witz has the same effect, in diminishing the wall action. The more rapidly the walls are uncovered, the less time is allowed them to act on the gases, and carry off the heat. At the same time rapid and complete expansion does not always mean a proportionate utilisation of the heat supplied to the engine. M. Richard shows by the figures given in the Society of Arts' Trials that in the Atkinson engine, where expansion is greater in proportion to admission and compression, the heat carried off by the walls, that is, during the expansion stroke, is relatively small, but more is discharged to the exhaust than in engines having a less expansion. It the two items of heat expenditure be added together (see table, p. 252), they will be found almost the same as in the Otto engine tested at the same time.

2. To diminish this great action of the walls, and to equalise their temperature and that of the gases, it is necessary to raise the temperature of the one, or lower that of the other. To raise the temperature of the walls is impossible, without injury to the engine. But by diluting the charge of gas with air to the limit of inflammability, and by utilising the inert gases, the heat of explosion may be diminished, without affecting the efficiency of the engine. This diminution of the maximum temperature is the reason of the comparatively high efficiency obtained in practice, with engines having combustion at constant pressure. As there is no very sudden rise in temperature, less heat is carried off by the walls, and more remains to do work on the piston.

3. The third is perhaps the greatest source of waste of heat in an engine cylinder. The most effectual method of diminishing the wall action is by previous compression of the charge. In

M. Richard's opinion it is only by this means that the losses of heat can be sensibly reduced, because compression diminishes the volume of the gases exposed to the cooling influences of the walls. Other conditions being equal, the larger the cylinder, the smaller will be the loss to the walls, because the smaller their area relative to the volume of the gases. As a result, less heat will be lost per cubic foot of gas to the walls and water jacket.

Loss of Heat.—But however carefully an engine may be designed, to keep the temperature and pressure of the charge within practical limits, all authorities are agreed that the greater part of the heat in a gas motor is lost by radiation and conduction, or discharged at exhaust. These are the two great sources of waste. If the heat accounts of the four engines given at p. 252 be compared, it will be seen that the jacket water and the exhaust carried off between them from 65 to 75 per cent. of the total heat developed. In the opinion of so competent an authority as M. Richard this waste cannot, in our present state of knowledge, be avoided. The heat economised from the one is usually wasted to the other. If the losses from the walls be diminished, the heat of the exhaust gases is increased. Nor is it possible at present to prevent the loss to the jacket to any great extent.

Notwithstanding every effort to determine the right mixture of gas and air, and to obtain complete combustion, as far as possible, the actual pressure in a gas engine is seldom more than about half the calculated. As pressure is always in strict proportion to heat, this deficiency, shown by the indicator diagrams, proves that much of the heat contained in the chemical constituents of the gas, and which ought to be liberated by their combination with oxygen during combustion, is either carried off, or not evolved. If all the heat were developed at the moment of explosion, and expended in doing work on the piston, the curve representing the expansion of the gases would be adiabatic. The line of expansion would follow the theoretical line of Carnot's cycle, and exhibit heat neither added nor abstracted, but solely employed in doing work. That this does not take place in practice can be seen, by comparing theoretical with actual diagrams. The difference between them is considerable. The line indicating the decrease in temperatures consequent on expansion is much higher in the theoretical than in the actual diagrams.

Variations in Expansion Curve.—The Otto diagram at p. 246 shows a peculiarity in the pressures obtained in the cylinder of later compression engines, which has not hitherto been satisfactorily explained. The fall of the expansion curve in the theoretical is, as we have said, more rapid than in an actual diagram. This theoretical curve represents exactly the fall in pressure, and therefore in temperature, which would be obtained, if the gases expended their heat entirely in doing work. If the

curve of the actual diagram is flatter, and does not fall so rapidly, this difference shows that the pressure does not in practice sink so quickly, and heat is not parted with as speedily as in theory. The law of the mechanical equivalent proves that the amount of heat expended in doing work does not vary, but is always the same, in practice as in theory. If, therefore, the pressure and temperature do not fall so rapidly in an actual engine, heat is added in some way. This addition of heat is obtained either from within or from without. Most authorities maintain that it is evolved from the mixture itself, because the walls of the cylinder, cooled by the water jacket, must always be at a lower temperature than the gases they enclose, and cannot convey heat to them. In considering the difference between inflammation and combustion, it has been shown that the moment of maximum explosion or pressure does not always agree with that of complete combustion. The two operations are not simultaneous. The gases may reach their maximum pressure, and the particles be driven widely apart by the flame spreading through them, before their perfect combination with the oxygen of the air, and reconstitution as CO_2 (carbonic acid) and H_2O (water vapour). This is the phenomenon which is now acknowledged by most scientific men to take place in the cylinder of a gas engine, and to cause the addition of heat shown in the slow fall of the expansion curve. The gases continue to re-combine and evolve heat after the period of maximum inflammation and pressure, and while the piston has already begun to move out by the force of the explosion. This chemical action is faithfully reproduced in the indicator diagram.

Equilibrium of Heat.—It is generally admitted that, in the cylinders of almost all direct-acting engines, with explosion at constant volume, this "equilibrium of heat," as it has been called, takes place. Heat is suppressed at the maximum temperature of explosion, to be evolved afterwards, during the expansion stroke. In many gas engines the expansion curve falls rather more rapidly than in the Otto diagram at p. 246. Even then, however, so much heat is carried off by the walls, that there could be no approximation to adiabatic expansion, unless heat were in some way added, to counteract the wall cooling effect. The phenomenon is described in German by the expressive term "nachbrennen." In English it is called "slow combustion," but it would be more correct to term it "after combustion." The fact is now well established, but the causes of this "after combustion" of the gases are still uncertain, and the following theories have been advanced to account for it.

Stratification.—The first was put forward by Otto, because it was in the diagrams of his engines that the effect of this "after combustion" upon the expansion curve was first studied. He claimed it as a direct result of the stratification of the charge, one of the improvements specified in his patent of 1876.

Instead of admitting the gas and air together through valves, as in later engines, the admission ports of the Otto were so arranged, that the air entered first. The gas valve then slowly opened, and the air was diluted with gas, the mixture increasing in percentage of gas as it continued to enter the cylinder until, the air port closing, nothing but gas was finally admitted. The products of combustion were not expelled from the cylinder, but remained and combined with the air in front of the fresh charge, to form a sort of cushion between the richer mixture and the piston, and to deaden the shock of the explosion. Thus between the piston and the ignition port there were—1, Products of combustion. 2, Pure air. 3, Air diluted with gas. 4, Gas only. According to Otto, combustion is very rapid at first through the explosive charge nearest the admission port. It spreads more slowly through the poorer mixture, because of its greater dilution with air, and with the products of the former charge (which MM. Berthelot and Vieille's experiments have proved to retard combustion), and hence the whole heat is not developed at once. Not only did Otto recognise the existence of the phenomenon of "after combustion," but he endeavoured to utilise it. In his opinion, this chemical burning process was under control, and might be produced at will, and turned to advantage by stratification of the charge.

This theory was supported by experiments made on an engine at the Otto Deutzer Gas-Fabrik. A glass chamber or prolongation was added to the cylinder of the engine at the admission end, and cigarette smoke was introduced into it by the momentary opening of a cock, when the piston was at the inner dead point. The movement of the smoke could be watched through the glass. Instead of passing through the cylinder and impinging against the piston, it remained near the admission cock, and only the back part of the cylinder was filled with it, even after the crank had made several revolutions. Some however were not convinced by this experiment that the admission of the mixture into the cylinder could be regulated at will, and other trials were made on a 4 H.P. engine by Professors Schöttler, Teichmann, and Lewicki, to determine whether stratification of the charge actually existed or not. In these, admission was effected as usual through an ordinary slide valve. Ignition took place at the back of the cylinder, but there was also a special arrangement, by means of which the charge could be ignited at the side only, behind the piston, and in front of the compression space. As long as the ordinary ignition at the further end was used, indicator diagrams were obtained, similar to the one at p. 246. But when the mixture was ignited at the side, the brake horse-power, representing the work actually done by the engine, sank to half the normal power, and the diagrams showed a great diminution in the pressure, and retardation in

the time of maximum explosion. The ignitions obtained were uncertain, often failed entirely, and were always too late. Analyses of the gases, taken from different parts of the cylinder, were also made by Professors Dewar and Teichmann, and it was found, as might have been expected, that their chemical composition in the lighting port, at the end furthest from the piston, was much richer than in front of the compression space. With a strong mixture, Teichmann found that the charge contained 16·2 per cent. of rich gas in the igniting port, 13·3 per cent. in the centre of the compression space, and 9·1 per cent. close to the piston.

The theory that stratification of the charge, which these experiments were undertaken to prove, caused the effects of after combustion has now been abandoned. Professor Schöttler and other scientific observers have pointed out that smoke cannot be considered as fairly representing the gaseous charge in the cylinder of an engine. Nor does it always remain at the back of the cylinder; in experiments undertaken by him on a Koerting engine, the whole cylinder was filled with a cloud of smoke. That ignition at the side proves stratification of the charge has also been disputed. It shows that the mixture is richer in some parts than in others, which might naturally be inferred under any conditions, but not that the gas remains in layers after introduction, although such a disposition is imparted to it at first. In experiments made on a Benz engine, under the same working conditions as the Otto, this partial stratification was not found to exist, and the charge was ignited with equal certainty at various parts of the cylinder. The latest authorities on the subject maintain that stratification cannot be preserved, even if the gases enter the cylinder in successive layers of richness, because of the compressive and mixing power exerted by the back stroke of the piston. It is impossible, they say, to conceive that the charge can adhere to the original order of its admission, when the rapidity with which the piston compresses it is considered, and even if stratification were proved, it is not sufficient to explain "after combustion."

M. Richard is, however, of opinion that there is an evident gain in efficiency if the products of combustion remain in the cylinder, although the actual stratification is not preserved. In the first place, to retain the burnt gases does not weaken the succeeding explosion if care be taken, as in the Otto engine, that the richest part of the mixture lies round the ignition port. Without any attempt at regular stratification, the products of combustion will naturally be disposed round the piston, and act as a cushion to deaden the shock of explosion. Again, these inert gases are at a high temperature, and if they be left in the cylinder, instead of being carried off to the exhaust, more heat

remains to increase the pressure and expansion, and less is discharged.

The increase in economy obtained with the new (1894) "scavenging" Crossley-Atkinson engine appears effectually to refute the theory that stratification of the charge, and retention of the products of combustion, add to the efficiency of a gas engine. It is true that these inert gases heat the incoming charge, but their effect is distinctly injurious, and probably contributes to the premature ignition which is so troublesome in large motors. It is difficult to account wholly for the saving effected, except on the assumption that a gain in efficiency is the result of cleansing the cylinder completely of the burnt products. Mr. W. Beaumont is of opinion that, "even with comparatively small engines, the complete discharge of residual products, and the perfect mixing of the gas and air, have already done more for economy" than any other improvement.

Mr. Dugald Clerk, in a valuable paper on "Recent Developments in Gas Engines," read before the Institution of Civil Engineers, January 28, 1896, discusses the causes of greater economy in modern engines, and the success obtained in the new "scavenging" motor. According to his view compression is an all-important point, more compression meaning more, and less compression less economy. He also considers it essential to diminish the volume of the ports and clearance, and especially to reduce their surfaces to a minimum, in order to lessen the weight of metal heated and cooled per motor stroke. In modern gas engines the dimensions of the clearance volumes and surfaces have gradually decreased year by year. He states the actual heat efficiency of the best modern engines at about half the possible theoretical efficiency, so that there is still much room for improvement. Although not mentioned in Mr. Clerk's paper, it should not be forgotten that the best standard of comparison between different gas engines is the thermal efficiency, and in calculating it the B.H.P. should always be taken, in preference to the I.H.P., to estimate the work done. This thermal efficiency varies slightly with the size of the engine, the smaller motors giving rather less. Coming to a consideration of the Crossley-Atkinson engine, upon which he made a very careful trial, Mr. Clerk arrives at the conclusion that the scavenging blast obtained by the use of a very long exhaust pipe, and by admitting air before the gas, while the exhaust is still open, effectually cools the cylinder. By carrying off the burnt products it prevents premature ignition, and increases the compression pressure of the fresh pure charge, and the power of the engine. The latter is, in Mr. Clerk's opinion, the chief cause of the economy, the advantage obtained by the scavenging charge alone not being more than 5 per cent. with lighting gas. The

maximum initial pressure in the best diagrams taken by him was 315 lbs. and the maximum compression pressure 90 lbs. The maximum heat efficiency of the Crossley-Atkinson engine is about 28 per cent.,* taking the I.H.P., as compared with 21 per cent in the Crossley-Otto engine of 1888. The gas consumption of the new motor is 17 cubic feet of Manchester gas per B.H.P. hour.

Mr. Clerk also gives a description of an interesting new engine lately designed by him, with one cylinder and two pistons, one single, the other double acting. For a description the reader is referred to Mr. Clerk's paper, already quoted.

Dissociation.—The next theory to account for the phenomenon of "after combustion" has been advanced by Mr. Dugald Clerk. He attributes it to the chemical action known as "dissociation." At certain high temperatures chemical compounds decompose, or separate into their constituent elements, and do not recombine until the temperature has fallen. Thus heat, which is one of the great forces in combining chemical elements, is also a powerful agency in splitting up compounds. The existence of this phenomenon has been repeatedly verified. Without it, it would be possible, during the combustion of gases, to reach much higher temperatures than have ever been attained in practice. If, for instance, steam be raised to a very high temperature, it ceases to be steam, and decomposes into its elements of oxygen and hydrogen. The higher the temperature, the more complete the dissociation, until a point is reached, above which all gases exist only as primary elements. The temperatures of compound gases, therefore, are probably limited, though the extent of this limitation has not yet been determined. Without dissociation it should be possible in theory to raise the temperature of hydrogen burning in oxygen to 9000° C., but no experiments have, to the author's knowledge, been made, in which a temperature of 3800° C. has been exceeded. Clerk maintains that, at the temperatures produced in a gas engine dissociation takes place, and checks the further development of heat, and this opinion is shared by Professors Ayrton and Perry. The gases decompose, their heat is suppressed, and not evolved until, the temperature being lowered by expansion, the chemical elements are able to recombine. If dissociation existed in the cylinder of a gas engine, its action would be as described by Mr. Clerk. Most scientific men, however, are now agreed that the estimate of temperature on which the theory is based is incorrect. Mr. Clerk, following Déville, is of opinion that dissociation commences at a temperature of from 1,000° C. to 1,200° C. Since the results of his researches were published, it has been proved by

* The heat efficiency is the per cent. of heat turned into B.H.P. to the total heat in the gas used.

the experiments of Mallard and Le Chatelier and others, that dissociation takes place at much higher temperatures than those in a gas engine cylinder. For carbonic acid it is perceptible at 1,800° C. and is less than 5 per cent. at 2,000°, but with steam, dissociation only appears at a temperature above 2,500° C. and at 3,300° C. it is still very slight. The highest temperature in a gas engine is probably never above 1,870° C. Abs. It is impossible, therefore, to account for the phenomenon of "after combustion" by the theory of dissociation.

Cooling Action of Walls.—Professor Witz has advanced another theory to explain it, and supports his view with the weight of his scientific reputation and experience. He attributes the variation of temperature shown in the slow fall of the expansion curve, and the suppression and retarded evolution of heat, entirely to the cooling action of the cylinder walls. To this he refers all the phenomena hitherto obscure in the cylinder of a gas engine. He is of opinion that this cooling effect has been neglected hitherto, and that, next to the charge itself, the walls play the most important part in the cycle of an engine. By carrying off the heat generated at the moment of explosion, they instantly diminish the temperature. Although continually cooled by the jacket, they act as reservoirs, and actually restore to the gas, during the latter part of the stroke, some of the heat they had previously absorbed.* In the earlier gas engines, without compression or ignition at the dead point, and with a much smaller range of temperature, the effect of the walls, though ignored, was very great. In modern engines this effect is greatly restricted, with the result, according to Witz, that the walls are able to refund heat to the gas during the expansion stroke.

Professor Schöttler agrees with Witz as to the marked effect produced by the walls. He is of opinion that the phenomenon of "nachbrennen" may be in part attributed to heat actually restored by the walls, and specially by the piston, to the hot gases. He suggests that the heat evolved by the combination of the chemical elements is transmitted, at the moment of its development, through the walls to the water, and that there is a fraction of a second during combustion when the temperature of the walls is actually higher than that of the gases they enclose. The effect would be the continued development of heat along the expansion line, after the attainment of maximum pressure.

Increase of Specific Heats.—A fourth solution of the problem has been suggested by MM. Mallard and Le Chatelier. From various experiments they have made, they are of opinion that the specific heats of gases increase at very high temperatures,

* The opinions of Professor Witz here given touch, in the author's opinion, upon debateable ground.

and that this increase may in part account for "after combustion." The subject is still in the stage of investigation, and no very positive determinations have, we believe, yet been made.

Whatever the causes producing the phenomenon of "nachbrennen," there can be no doubt that it is in itself injurious, and not, as Otto considered, advantageous. The suppressed heat, although ultimately developed, is not evolved at the right time, and therefore cannot contribute to the maximum pressure of explosion. In practice and in theory the full utilisation of the heat supplied to an engine depends on the range—that is, the maximum temperature of explosion, and the minimum temperature of exhaust. Whatever checks the attainment of this maximum temperature has an injurious effect on the efficiency of the engine. The difficulties of the subject have been ably summed up by M. Richard in the following words:—

Cylinder Wall Action.—"No satisfactory answer has yet been found to the question: What is the cause of the loss of heat during explosion and expansion? It cannot be denied that it is partly caused by the action of the walls; they have an influence which, if studied alone, may almost be formulated as a law. But is the effect of the walls varying or constant? To what extent does it intervene, during the motor stroke, in the other phenomena? These are,—the increase of specific heat at the temperature of explosion (not yet universally admitted);—dissociation, a phenomenon rather suspected than proved;—combustion continuing during expansion, which some deny and others vehemently affirm. If it exists, as in my opinion it does, it is a result of the composition of the charge, compression, and the method of ignition. In a word, it is a most complex phenomenon, not only in itself, but because it is connected with all the actions simultaneously produced during the short period of a motor stroke. . . . The experimental theory of the gas engine has not yet been made. . . . Like that of the steam engine it cannot be determined without experiments, but it is of such importance that it ought to be undertaken, without shrinking from the toil and difficulty, the length and cost of the study it involves."

The Author is of opinion that the cylinder wall action in gas, as in steam engines, is very considerable, and it may be well to compare this action in the two types of motors. In the case of a single-acting horizontal four-cycle gas engine with water jacket, the difference of temperature between the gas and the metal is greater than between the steam and the metal in a steam engine. In gas engines heat goes through the metal walls nearly always in one direction, from the centre of the cylinder outwards. There is a greater flow of heat at the explosion end of the cylinder and in the large clearance areas, because the temperature and pressure are greater than at the other non-explosion end. During the three

non-motor strokes, the heat would travel through the walls much less rapidly, and the temperature of the metal would tend to become uniform. In a steam engine the wall action fluctuates periodically in the thickness of the metal, first in one direction, then in the other. During the steam stroke, heat passes from the hot steam to the cooler walls, and during the exhaust, from the hotter walls in the reverse direction.

In a gas engine, during the explosion and expansion stroke, the heat passes rapidly doubtless from the hot gases to the cooler walls, which, on the side touched by the water, are at a temperature of say about 150° to 180° F. The temperature of the gases will vary from say 1,800° to 2,500° F. If we assume an average of 2,000° F., there will be a difference of temperature of about 2,000° – 150° = 1,850° F. between the gases and the metal next the water, causing the heat to flow through the walls to the cooler circulating water.

During the exhaust stroke the gases are still much hotter than the walls, and the heat flow will be in the same direction, but less energetic. During the admission stroke of cold gas and air, the movement of heat will either be reversed or nearly suspended, as, by the time the charge has actually filled the hot cylinder and clearance, there will no doubt be little difference in temperature between it and the walls. During the compression stroke, there will be a tendency for the heat to pass again to the walls from the gases. We may thus assume that the flow of heat, though varying much in intensity, is generally from the internal to the external surfaces of the cast-iron walls, or from the hot gases to the cooler water.

At the explosion end of the cylinder the clearance surfaces will, to the thickness perhaps of a sheet of paper, approximate to the temperature of the dry gases. The lubricating oil will act as a non-conducting film, and tend to check the flow of heat. Nor must it be forgotten that, according to the opinion of the best authorities, the centre of the charge is much hotter than the parts in contact with the walls. The flow of heat may, therefore, commence from a hot nucleus in the middle of the cylinder. The thickness of the metal walls will vary, say in different sized engine cylinders, from 1 to 1½ inch. As the metal at the explosion end will be much hotter than at the other end, there will probably be a flow of heat horizontally through the thickness of the wall towards the crank, as well as the flow radially from the hot gases. These two movements of heat will probably form a thermal gradient slightly inclined to the axis of the cylinder.

Effect of Time.—Again, there is the question of time influencing the wall heat action. Taking two motors running at different revolutions per minute, the engine with the slower piston speed will give the water and the gases more time to interchange their heat than the quicker running engine, in which a

shorter time per stroke is allowed. The quantity and speed of jacket water passing per minute round the cylinder, to cool so many square feet of internal surface, is another factor of this complicated wall action. In other words, the number of lbs. of water passing per minute through the jacket per square foot of internal surface should always be considered, as well as the action of the metal of the piston. As the clearance area exposed to the hot gases is much larger in gas than in steam engines, these important surfaces should, in accurate experiments, be given in square feet, as well as the cylinder volume. During the different strokes violent movements will take place inside the cylinder, particularly during the explosion stroke, when the whole cylinder is probably filled with flame.

M. Richard maintains rightly that experiments are much needed to determine the temperature of gas engine walls, of which so little is known.

Professor Kennedy shares the opinions of most other scientific men as to the great future possibilities of the gas engine. In a lecture delivered at the Royal Institution (in April, 1893), on the "Utilisation of Energy," he places the theoretical efficiency of coal gas at 80 per cent. Of this a gas engine, he says, utilises from 22 to 32 per cent. The waste of heat is chiefly due to the jacket, because, owing to the high temperature of the working agent, we have, in Professor Kennedy's words, to "adopt the somewhat barbarous expedient of continually keeping the metal cool by means of a water jacket."

PART II.

PETROLEUM ENGINES.

CHAPTER XX.

THE DISCOVERY, UTILISATION, AND PROPERTIES OF OIL.*

CONTENTS.—Petroleum; Its Production in Russia, America, and Scotland — Composition — Distillation — Density — Flashing Point — Heating Value—Evaporation—Pressure—Utilisation of Oil—As Liquid Fuel on Railways, &c.—Oil Gas—Mansfield Producer—Keith—Rogers—Pintsch.

THE name petroleum, or rock oil, is derived from the Latin words *petra*, a rock, and *oleum*, oil. It is a mineral product, obtained from the earth in two different ways. Most of the oil used is drawn, at varying depths, from subterranean wells in a natural state, but a relatively small quantity is also produced by distillation from bituminous shale. The extraction of oil has been carried on in Scotland since 1850; the discovery of rock oil in the earth, and the operations necessary for bringing it to the surface, date from a few years later. A third kind of oil, which must be distinguished from these, is obtained from fat and grease, by the application of intense heat, in retorts. The process is usually continued until the oil has been converted into a rich gas. Lastly, there are vegetable oils, such as linseed, castor, palm, or olive oil, from which gas may also be produced by distillation. To distil gas from any kind of oil, great heat is necessary.

Petroleum.—Within the last few years petroleum has become a most important article of commerce. There are two countries from which this oil has been chiefly obtained, the shores of the Caspian Sea, and the centre of the United States. It is known, however, to exist in many other places, and has been found in South America, especially in Peru and the Argentine Republic, India, Assam (1890), Beloochistan, Japan, China, Burmah, Egypt, Australia, and in the south-east of Europe. Some scientific men are of opinion that petroleum may be discovered almost everywhere, if the borings are carried deep enough into the

* Students desirous of investigating this important subject with special reference to the geographical and geological distribution of petroleum throughout the world, its refining, characteristics, uses and testing, are referred to Mr. Boverton Redwood's valuable work on *Petroleum*. (Griffin and Co. 1896.)

earth. But for the present the supply from Russia is, and will probably long continue to be, practically unlimited, and Russian petroleum is conveyed so cheaply all over Europe, that it is not worth while to seek for oil elsewhere. The chief centre of the oil industry is round the shores of the Caspian, though important oil fields have been discovered in Central Asia. It is only within the last twenty-five years that these vast natural reservoirs have been utilised, and their discovery threatens in several ways to revolutionise commerce, especially as providing a new kind of fuel. The town of Baku, the capital of the Caspian district, has from a village become a large and flourishing city, since oil has been found in great quantities in its vicinity. The existence of an oil region round the Caspian was known from the earliest times. The district was called by the ancients the Fire Region, and the mysterious flames which issued from fissures in the rocks were worshipped by them 600 years B.C., as manifestations of the Fire God. These flames are nothing more than the gases given off by the subterranean oil reservoirs, ignited at some remote period, and which have never been extinguished.

Russian Oil.—The extraction of oil from the earth in the Baku district is now carried out on a regular system. The wells are tapped, or the oil is "struck," as it is called, and immediately rises to the surface at a high pressure. It is then conveyed through pipes direct to the refineries, where it is purified, and separated into the lighter volatile oils, as naphtha, the lighting or intermediate oils, lubricating oils, which are all of varying density, and the crude petroleum called "astatki." Through another line of pipes it is next carried to fill the tanks in the steamers on the Caspian, no other method of distribution being employed. This system of pipes forms a network over an area of several square miles round Baku, and the oil issues from the wells at so high a pressure that no pumping is required, until the flow has begun to diminish. It is struck at a depth varying from 70 to 825 feet below the surface. A new line of pipes is now in course of construction, for carrying refined oil from Baku through the Caucasus to Batoum, on the Black Sea, 560 miles distant, from whence it will be easy to convey it by sea to the south of Russia, and throughout the countries bordering on the Mediterranean. The oil industry of Baku has been greatly developed, and almost created by two Swedish engineers, Robert and Ludwig Nobel, who have organised a system of obtaining and refining the oil, and distributing it all over Europe (see Appendix, Section A).

American Oil.—The second source of oil supply is from Pennsylvania and the Alleghany district in North America, and the newly discovered oil regions of Athabasca in Central Canada. Here also the supply is ample, though the borings are carried much lower, oil being usually found at a depth of from 500 to

4,000 feet from the surface. The petroleum wells of Pennsylvania were discovered about 1859. The oil issues from the ground at a lower pressure than in the Caspian district, and is pumped through pipes, often hundreds of miles in length, to the chief commercial centres of the United States. There are about 25,000 petroleum wells in America, and 400 in the Caspian, but the supply in the latter is very much more abundant. In 1890 the yield of oil from the American wells was 2,600,000 gallons a day, and from the Caspian nearly 2,700,000 gallons per day. The supply from both is at present apparently unlimited, and there are only two drawbacks to the use of petroleum all over the world, for lighting and heating purposes, &c. The first is the cost and difficulty of transport, which will no doubt be overcome; the second is the varying composition and inflammable nature of the oil, necessitating great care in carrying and storing it.

Scotch Oil.—The third source from whence mineral oil is obtained is by distillation from bituminous shale or "petroleum peat." Dr. James Young was the first to discover, in 1850, that petroleum could be extracted from shale, rich beds of which exist in abundance in Scotland. The oil produced is usually known as paraffin oil.

Thus during the last forty years a vast and hitherto unsuspected store of natural fuel has been brought to light, which, unlike coal, requires no laborious mining process to extract it from the earth. It is merely necessary to bore a well of the requisite depth, with an instrument known as a well-driller, over which a wooden structure is erected, and the oil issues forth in a liquid stream. The boring is often now carried out by a motor driven by oil. Care must be taken, however, in the Caspian district, that the flow of oil is not allowed to become so great as to flood the country. Thus in the Droojba fountain, in 1883, the oil rose to a height of 300 feet, and flowed at the rate of 2,000,000 gallons a day. It burst to the surface with the force of a miniature volcano, carrying with it large quantities of sand, and the damage done to the surrounding country ruined the owners. About £10,000 worth of oil per day were thrown up, and most of it wasted. To check this tremendous flow, the wells are now "capped" at once if possible, and frequently covered over, or "corked," if the price of oil is at the time so low as to render the working unrenumerative. Thus the supply is stored for future use.

Composition of Oil.—The difficulties of utilising Nature's bountiful stores of light and heat become apparent, as soon as the chemical constituents of the oil are examined. The composition of fuel such as coal, wood, &c., varies considerably, and with oil it is even less uniform. Crude petroleum consists of various hydrocarbons, differing in their proportions in every oil,

and all are of different densities. The density of some is very low, and they are much lighter than water, taken as unity. The lighter the more dangerous the oil, because the more rapidly it evaporates, giving off inflammable vapours which ignite if a light be brought near. As the chemical constituents of petroleum have different boiling points, they are vaporised at different temperatures. Hence the difficulty of dealing with these oils. At a low temperature the lightest and most volatile hydrocarbons rise to the surface, and are first given off. As the temperature increases, and more heat is applied, the heavier and more inflammable vapours are separated, till at last all the volatile oil is evaporated, and a thick heavy liquid is left, called "astatki" in Russia, and "residuum" in America. Formerly this petroleum refuse was considered useless, and thrown away. Both in America and Russia it was allowed at times to run to waste, and formed lakes of liquid petroleum, which were often set on fire, to get rid of them, or carried off by pipes into the sea. It is now known that, though this refuse cannot be volatilised by the application of heat, however intense, it may be broken up or divided into spray and utilised, by injecting air or steam into it, and thus burning it. It is used extensively in Russia and America, and forms a valuable liquid fuel, though it does not yet pay for the cost of transport to other countries.

Distillation.—If American, Russian, or Scotch shale oil be heated gradually in a retort, it is divided up by what is called "fractional distillation" as follows:—The highly inflammable vapours, variously known as naphtha, gazolene, benzoline, petroleum essence, petroleum spirit, &c., are first given off. These vapours, though very dangerous, are free from impurity. As the temperature of the retort increases heavier gases are liberated, and carbon is deposited; while at a red heat the residuum is split up, or "cracked," and converted into a true oil gas, containing a large amount of tarry products. "Cracking" is the term applied to petroleum when, by subjecting it to great heat, the heavier chemical constituents, which will not themselves vaporise at that temperature, are split up and decomposed into lighter hydrocarbons, which are readily evaporated. The different oils thus formed are, in the order of their density, volatile essence or spirit; kerosene or illuminating oil; what is called intermediate oil, because in density and inflammability it is between the light and heavy oils; thick lubricating oil; and lastly, *astatki* or refuse, which may either be made into gas, or by the addition of superheated steam, burnt as fuel.

Different Densities of Oil.—It must not be supposed that these different classes of oil are ever rigidly defined in any petroleum. They pass one into the other, from lighter to heavier, by imperceptible gradations, and can only be correctly tabulated according to their density. Nor is even this an

infallible test of their quality, for the same oil, naphtha, kerosene, or lubricating oil, will often vary in density, according to the petroleum from which it is obtained. Sometimes an oil will contain more of the lighter, sometimes more of the heavier constituents. At Baku the lightest oils are found in wells of great depth, and hence the high pressure of the oil fountains, and the force with which they rise; the heavier kinds lie nearer the surface. The difficulty caused by the varying density of petroleum, and the different temperatures at which it vaporises, is the main obstacle to its use in heat engines, and special means are employed in every case to convert it into spray. If the oil be simply injected into the cylinder like gas, the hydrocarbons are soon deposited, and are troublesome to get rid of. If only the lightest oils or spirit are used, they are even more easily ignited than gas, but they are expensive, and dangerous to transport. Legally they can only be used with special precautions in heat motors. The heavy liquid refuse is not inflammable, and therefore quite safe, but to employ it in an engine it must be previously distilled in a retort. It is the intermediate kinds of oil, obtained from heavy residuum after refining away the volatile essence, which are chiefly used for lighting and heating; and petroleum, as distinguished from spirit or naphtha, motors, are usually driven by these oils only. If natural oils have been carefully refined, and their more volatile constituents drawn off by the application of heat, they become much less inflammable. Lighting oil or common kerosene will not ignite at the ordinary temperature, and will even extinguish a lighted taper when applied to it. Special legal restrictions are, however, placed on the use of oil in most European countries, and a test, known as the Flashing Point, is prescribed, to determine its inflammability.

Flashing Point.—The flashing point of an oil is the temperature at which it gives off inflammable vapours, and depends on its density or specific gravity—that is, the ratio of a given volume of its weight, as compared to the weight of the same volume of water, at the ordinary temperature of 60° F. Careful allowance must always be made for temperature in dealing with oil, because petroleum increases greatly in volume with every degree rise of heat. To determine its specific gravity, water is taken as unity, and the weights of oil as fractions. The higher the specific gravity of oil, or the more closely it approximates to the density of water, the less danger will there be of its inflammability. Petroleum which has a low specific gravity contains very light chemical constituents, and these are given off at a low temperature. Hence it catches fire more readily than other oils of greater density, containing heavier hydrocarbons.

The flashing point of oil is usually determined by means of an apparatus designed by Sir F. Abel. A small cylindrical

vessel of oil is immersed in another containing water. The tight fitting cover of the small oil vessel has three holes, which are opened by moving a slide. Through one a thermometer is passed into the vessel, and a gas burner and flame are fixed above the others. The oil is heated by raising the temperature of the water in the receiver by means of a lamp. At about 66° F., or 19° C., the slide in the cover of the air vessel is slowly withdrawn, the flame tilted till it is brought beneath the lid through the holes, and the oil watched until it lights or flashes. The flashing point is determined from the number of degrees rise in temperature of the oil. In most countries of Europe and America no oil may be used giving off inflammable vapours, that is having a flashing point below a certain limit of temperature, which is fixed by law. In England and Canada the limit is 73° F., or 22° C.; in America and Austria, 37·5° C.; in France, 35° C.; Russia, 28° C.; Germany, 21° C. The flashing point may also be roughly determined by holding a lighted taper above an open vessel filled with oil. As the temperature is raised by the heat of the taper, light hydrocarbons are liberated, rise to the surface and ignite, and if a thermometer be placed in the oil, the flashing point can be read off. The higher this limit of ignition, the safer the oil.

Ignition Point.—The ignition or burning point of oil is the temperature at which the oil itself, and not the inflammable

TABLE OF CONSTITUENTS OF AMERICAN, RUSSIAN, AND SCOTCH SHALE OIL, WITH SPECIFIC GRAVITY AND FLASHING POINT (*Robinson*).

Constituents.	American Oil.		Russian Oil.		Scotch Shale Oil.		Flashing Point.
	Volume.	Specific Gravity.	Volume.	Specific Gravity.	Volume.	Specific Gravity.	
	Per cent.		Per cent.		Per cent.		Degrees C.
Benzine light oils,	14	0·700	1	0·725	5	0·730	– 10
Benzine heavy oils,	2	0·730	3	0·775	...	...	0
Kerosene lighting oils, . .	50	0·810	27	0·822	35	0·805	25 to 50
Intermediate, .	...	...	12	0·858	2	0·850	105
Lubricating pyro-naphtha oils,	15	0·880	32	0·903	18	0·885	110 to 200
Paraffin wax (vaseline), . .	2	...	1	0·925	12	...	...
Residuum and loss,	16	...	24	...	28	...	...
	99		100		100		

vapours given off, takes fire. It is of course of greater importance to determine the flashing than the burning point, the former being reached long before the oil itself is raised to the ignition point. As the lowest legal flashing point of an oil is in England 73° F., naphtha or petroleum spirit, which ignites at a lower temperature and is very dangerous, may not be used. The flashing point of astatki or crude petroleum refuse is above 200° C.; intermediate Scotch shale oil has a flashing point of 105° C. = 221° F.

The table on p. 280 (from Professor Robinson's *Gas and Petroleum Engines*) gives the proportions by volume, flashing point, and specific gravity, of the different hydrocarbons contained in Russian, American, and Scotch petroleum.

The following table (from Redwood, see p. 282) shows the chemical constituents of the oils from different countries and their heating value, &c.

Calorific Value of Oil as used in an Engine.—Mr. C. J. Wilson, F.S.C., the best London authority on this subject, has made many determinations of the heating value of oils with his improved fuel calorimeter, especially in connection with the Royal Agricultural Society's engine tests.

The heating value of oil is now usually determined in a closed calorimeter, but in applying this determination to the combustion of oil in a motor cylinder, the conditions are very different. When oil is burnt by means of compressed oxygen in a calorimeter, the whole of the water produced by the combustion of the hydrogen is condensed to the liquid state, and cooled to the temperature at which the experiment is made. It is therefore necessary to know the amount of this water, and deduct the heat which would be required to evaporate it, since in all cases where an oil is burnt as fuel, the products escape in the gaseous state. In an engine cylinder the water is discharged at exhaust as steam, and not condensed. This difference should be allowed for, in giving the useful heating value for oil in an engine, as heat is lost at exhaust, otherwise an error of about 7 per cent. may be made.

The following extract on the heat value of Russolene and Broxbourne oils, tested by Mr. Wilson, is taken from the Royal Agricultural Society's Report for 1894:—

"**Russolene Oil—Calorific Value.**—To determine this, the oil was completely burned in a closed bomb with compressed oxygen, and the heat produced carefully measured. Calculated to calories per gramme of oil, the mean of two concordant experiments is 11·055. This figure includes all heat obtained by condensation of produced water, and cooling this and the gaseous products to 28° C. In order to obtain a correction for the water produced by combustion, the percentage of hydrogen in the oil was determined, and found to be 14·05 per cent.; the produced

TABLE OF COMPOSITION AND HEATING VALUE OF OILS.

Description and Locality of Oil.	Specific Gravity at 0° C.	Chemical Composition.			Lbs. of Water evaporated per lb. of Fuel from 100° C.	British Thermal Units, per lb.
		Carbon.	Hydrogen.	Oxygen.		
		Per cent.	Per cent.	Per cent.		
Heavy petroleum from West Virginia,	0·873	83·5	13·3	3·2	14·58	18,324
Light ,, ,,	0·841	84·3	14·1	1·6	14·55	18,401
Light petroleum from Pennsylvania,	0·816	82·0	14·8	3·2	14·05	17,933
Heavy ,, ,,	0·886	84·9	13·7	1·0	15·30	19,210
American petroleum,	0·820	83·4	14·7	1·9	14·14	17,588
Petroleum from Parma,	0·786	84·0	13·4	1·8	13·96	18,218
,, ,, Pechelbronn,	0·912	86·9	11·8	1·3	14·30	17,474
,, ,, ,,	0·892	85·7	12·0	2·3	14·48	18,036
,, ,, Schwabweiler,	0·861	86·2	13·3	0·5	15·36	18,824
,, ,, East Galicia,	0·870	82·2	12·1	5·7	14·23	18,153
,, ,, West Galicia,	0·885	85·3	12·6	2·1 (N.O.)	14·79	18,416
Shale oil from Ardèche, France,	0·911	80·3	11·5	8·2 (O.S.N.)	12·24	16,283
Coal tar from Paris Gas Works,	1·044	82·0	7·6	10·4	12·77	16,049
Petroleum from Balakhany,	0·882	87·4	12·5	0·1	...	21,060
Light petroleum from Baku,	0·884	86·3	13·6	0·1	16·40	20,628
Heavy ,, ,,	0·938	86·6	12·3	1·1	15·55	19,440
Petroleum residues from the Baku factories,	0·928	87·1	11·7	1·2	...	19,260
Petroleum from Java,	0·923	87·1	12·0	0·9	15·02	19,496
Heavy oil from Ogaio,	0·985	87·1	10·4	2·5	14·75	18,146

water will, therefore, be 1·2645 times the weight of the oil. Taking the latent heat of water at 28° C., as 587 calories gives 0·742 calorie per gramme, and deducting this from 11·055 gives 10·313 calories as the heat of combustion of 1 gramme of the oil; products of combustion in the gaseous state at 28° C. This oil seems very constant in composition, for a sample examined more than a year ago gave 14·07 per cent. of hydrogen, and a calorific value of 10·3 calories per gramme,—practically identical with the above.

"The heat value is, therefore, nearly 18,600 British T.U. per lb. Comparing this with Welsh steam, with a calorific value of 14,500 thermal units per lb., one lb. of oil will, in heating value, be equivalent to 1·28 lb. of coal, and comparing it with London gas, having a calorific value of 19,200 British T.U. per lb., it would be equivalent to 0·97 lb. of gas. The specific gravity of this oil at 60° F. is 0·82, and flashing point (Abel test) 86° F."

"**Broxbourne Oil—Calorific Value.**—The mean of two experiments in the compressed oxygen calorimeter gives 11·019 calories per gramme, all produced water being condensed. The correction calculated from the hydrogen percentage is 0·742 calorie, giving as the heat value 10·277 calories per gramme, all products of combustion in the gaseous state at 24° C. This corresponds to a thermal value of 18,500 British T.U. per lb., the specific gravity of the oil at 60° F. being 0·81, and flashing point (Abel test) 155° F. The Broxbourne oil was about double the price of the Russolene."

Professor Robinson's Experiments.—A series of careful and interesting experiments were undertaken by Professor Robinson, to determine the nature of the changes produced by heat in different kinds of oil. In order to ascertain the properties of oil, and how much additional heat was necessary to convert it into a vapour before using it in the cylinder of an engine, he desired to know the temperature at which the oil distilled or evaporated, and the pressure of the petroleum vapour given off. The first point could only be determined by the process of fractional distillation. A glass flask filled with petroleum was placed in a sand bath, and slowly heated by the flame of a Bunsen burner. Two thermometers were used, one in the oil, the other at the neck of the flask. By this apparatus Professor Robinson was able to take the temperature of the oil, and of the vapour as it was given off; the latter was then passed through a glass tube surrounded with iced water into a graduated condenser. With water the boiling point would be always the same, but with oil it was necessary, as distillation ceased at one temperature, to increase it continually. The temperatures of the oil and vapour were found never to agree completely, but the higher the temperature of the

oil, the less difference there was between it and the temperature of the distilled vapour. A marked difference between the various oils tested was found, in the gradual or abrupt distillation of their constituents, and the percentage given off at the different temperatures. As a rule, Scotch shale oil distilled slowly at a high temperature, with the exception of Trinity or lighthouse oil, 55 per cent. of which distilled between 170° C. and 230° C. Some of the ordinary lubricating oils distilled rapidly at a temperature commencing at 120° C., the Russian at 130° C. The oils which distilled a large percentage of their volume within a limited range of temperature, showed a more or less uniform composition. Others evaporated slowly through a wide range, proving that they were more complex in composition, and made up of hydrocarbons having varying boiling points. Only a small percentage of the heavy, intermediate, and Scotch shale oils was distilled at a very high temperature. The range of temperature applied to these oils varied from 120° C. to 270° C. At a temperature of from 215° C. to 240° C., about 50 per cent. of the American and Russian oils distilled.

Evaporation of Oil.—The next experiments were undertaken to determine the evaporation from heavy oils in the open air, when exposed to a slow gentle heat, under ordinary atmospheric conditions, and thus the amount of light hydrocarbons they contained. Lighthouse, Scotch shale, and lubricating oils, having a specific gravity of 0·810 to 0·853, were tested. They were placed in shallow receivers, and a steady heat maintained beneath them, the temperature of the oils being kept for three hours at from 40° C. to 65° C. The amount of evaporation was determined by weighing the oils before and after the experiments, and it was found that the percentage of loss varied inversely as their specific gravity. With the heaviest lubricating oil, the loss in weight was 2·96 per cent., with the lightest oil of 0·810 specific gravity it was 6·90 per cent. in the same time. These experiments show the degrees of safety with which oils may be stored in hot climates, and the necessity of ventilating and keeping cool the oil tanks, thus diminishing risk and loss by evaporation.

Pressures of Oil.—Professor Robinson next endeavoured to determine the pressures of the different oils, corresponding with a given rise in temperature. Some difficulty was experienced in making these trials, because it was found much less easy to prevent leakage from the joints with petroleum vapour, than with steam or lighting gas. The testing apparatus consisted of a U-shaped glass tube, having one limb longer than the other. At the end of the shorter was a spherical bulb, the longer was provided with a graduated scale. The tube and bulb were filled with mercury and oil, the oil being uppermost in the bulb. The temperature was raised by placing the glass apparatus in a glycerine bath, gradually heated by a Bunsen burner. As

the sample of oil in the bulb increased in temperature, the pressure generated by its vapour forced the mercury down the bulb and up the longer limb of the tube, and its rise was noted on the scale. Corrections were carefully made for the temperature of the room, latent heat of evaporation in the oil, expansion of the glass and mercury, &c. The height of the mercury in the tube showed the pressure attained by the petroleum vapour in the bulb, corresponding to the rise in temperature of the glycerine bath. The results of the experiments were afterwards plotted on curves, showing the proportional increase of pressure with increase of temperature, in the same way as with steam. Professor Robinson gives various curves exhibiting the temperatures and pressures for different oils. It was found that steam had a higher pressure at a given temperature than any of the oils, except petroleum spirit or naphtha, the pressure of which rises more rapidly in proportion to its temperature. At 300° F. the pressure of petroleum spirit was 125 lbs. and that of steam is 55 lbs. per square inch. The pressure of ordinary oils was much less. Common lighting oils, chiefly American, gave an absolute pressure of a little above 150 centimetres of mercury, at temperatures varying from 170° C. to 200° C., while the heavy oils, as Lighthouse or Scotch shale, having a specific gravity of about 0·825, showed a very low absolute pressure,* 90 to 94 centimetres of mercury at a temperature of 200° C. The lighter the oil, the more nearly it approached the temperature and pressure of steam. At lower temperatures the oils exhibited great differences of pressure, but at the lowest temperature tested, about 80° C., all gave nearly the same pressure, viz., about 80 centimetres of mercury (absolute pressure). At temperatures below 100° C., the pressure of water vapour was very much higher than that of any oil.

The pressure of air at a given temperature being known, it is possible, with the help of these valuable tables, to determine approximately the temperature and pressure of petroleum vapour, and therefore the work which should be obtained from a mixture of oil and air in the cylinder of an engine. Much, however, remains to be done, and at present we know little about the action of petroleum under great heat in a motor. The difficulties of the subject are increased by the complex constitution of oil. The latent heat of evaporation of petroleum is about one-ninth that of water—that is, the same quantity of heat will evaporate nine times as much oil of average specific gravity as water, but the expansion of the vapour is only one-fifth that of water vapour or steam. Hence the same quantity of heat will produce $\frac{9}{5}$ or 1·8 times as much oil vapour as steam from water (see p. 319). The above data are from Professor Robin-

* Absolute pressure is 14·7 lbs. below the pressure of the atmosphere.

son's able lectures at the Society of Arts on "The Uses of Petroleum in Prime Motors," to which the student is referred for an exhaustive treatment of the subject. Professor Robinson has been the first, as far as the author is aware, to make a special study of this difficult question.

Utilisation of Oil.—Having thus considered the chemical composition and properties of oil, it will be evident that, though it can be utilised in many ways to produce heat, the process is complicated, because its constituents vary so widely. There are four methods by which petroleum may be used to generate mechanical energy in a heat motor.

I. As liquid fuel it is burnt under a boiler to evaporate water. In this case the petroleum is simply used as fuel, and produces the same effect. It is injected through a nozzle, with a proper admixture of steam and air, into the furnace, where it is burnt in the ordinary way. The heaviest petroleum and oil refuse may be thus employed to generate heat; the greater the specific gravity of the oil, the better suited it is for fuel.

II. Petroleum may be subjected to destructive distillation in a retort, and turned into a fixed gas, in the same way that lighting gas is distilled from coal. Any oil may be treated in this manner, but the best for distilling are the intermediate oils, which are neither so light that they escape before they can be gasified, nor so heavy that they cannot easily be broken up. The oil gas thus produced is exceedingly rich, having twice the heating value of coal gas. Mixed with air in proper proportions, this gas is introduced into the cylinder of an engine, and the force of the explosion drives the piston forward, as in a gas engine.

III. The lighter and more volatile constituents of petroleum, such as gazolene, benzine, petroleum spirit, essence or naphtha, are used, in the same way as oil gas, to work a motor. The spirit is previously prepared, and the heavier hydrocarbons withdrawn. Except that the power necessary to drive the engine is obtained by explosion, the action of the volatile spirit is similar to that of steam in a steam engine, the spirit being condensed, re-evaporated, and used continuously, as in the Yarrow spirit launch. The same spirit is also used as a fuel to vaporise the working agent.

IV. Ordinary petroleum is evaporated at a moderate temperature in an apparatus contiguous to the engine, and mixed with air is used, as in the spirit engine, to drive the piston by the force of explosion. Here also the oil constitutes both the fuel and the working agent. Engines employing this method to produce mechanical energy from petroleum may be divided roughly into two classes—(*a*) Those in which the whole of the crude petroleum is vaporised, and so broken up that practically no residuum is left; (*b*) Those working with oils of lower specific gravity, in which cold air is charged with the volatile hydrocarbons, and the heavy residuum wasted. Some of the latter may

almost be called spirit engines, as the oil they retain for use is very light and inflammable.

Various Methods.—All these methods of utilising petroleum as fuel present difficulties, owing to the complex nature of the oil, except when it is evaporated as a pure spirit. It was long thought impossible to burn the heavy astatki, but when converted into spray by injecting steam or air into it, it can under certain circumstances be profitably employed. When the petroleum is turned into a fixed gas, without the addition of air, difficulties arise, because the gas becomes laden with tarry products which, unless it is well washed and cooled, clog the pipes and valves. There is another obstacle when the lighter constituents of petroleum are utilised in an engine. These are given off at different temperatures, and the process is assisted if a large surface of the oil is brought in contact with the air. It is therefore agitated mechanically, the whole of the volatile constituents are gradually evaporated, and a heavy residuum remains, which is usually wasted. Some foreign inventors prefer to utilise only the lighter and more inflammable portions of the oil, and to sacrifice the remainder, thereby obtaining quicker evaporation, more power, and cleaner combustion than with heavier oils, though the consumption is greater. But the method more generally employed in oil engines, as safer and less wasteful, is to evaporate the whole of the oil, and this requires the application of heat.

We will now consider—I. Petroleum as fuel, and II. Petroleum when converted into oil gas. In the next chapter we shall treat of III. The use of Petroleum spirit, and IV. Crude petroleum in oil engines.

I. **Petroleum as Fuel.**—The advantages of petroleum, when burned as liquid fuel, are so great that it is safe to predict it will in time compete with coal and other fuels, and become an important factor in the commerce of the world. There are now on the Caspian forty "oil steamers," in which the boilers are fired with astatki. All the locomotives on the Tsaritzin and Grazi Railway in south-east Russia are fitted with an apparatus for burning petroleum refuse, instead of coal, under their boilers. Coal in that part of Russia being dear and scarce, the economy thus realised is considerable. In fact the Baku oil fields have created the Caspian fleet. The uses to which petroleum is now being turned in Russia, where the oil is obtained on the spot, will probably be extended to other parts of Eastern Europe, as soon as pipe lines have been laid along the Caucasus to the Black Sea.

Difficulties.—The difficulties attached to the use of petroleum as fuel are—first, its complex constitution; secondly, its inflammable nature; and thirdly, its cost. The two first do not apply to astatki or petroleum refuse. The heavy oil used on the Russian

railways is scarcely more inflammable than coal, and there is consequently no danger in using it. This was proved during an accident on the line, when an engine and carriages left the rails, and the tank of astatki in the tender did not ignite. The constitution of the petroleum is also fairly uniform, because all the volatile hydrocarbons have been evaporated, and though it is heavy and difficult to break up into spray, yet when combined with injections of steam and air it forms a safe and excellent combustible. At present, however, it can only be used in countries producing it, on account of the cost of transport. In England it is not likely to compete with native coal, but it may in the future be found in our Colonies and Dependencies, and there be turned to great advantage for locomotive and marine engines. The steamships of the Chilian Company use 100,000 tons of petroleum yearly. An abundant supply is found in Peru, and oil fields are also being opened up in Ecuador. In Scotland we have an almost unlimited quantity of shale, capable of yielding 120 gallons of oil per ton, but it is chiefly utilised at present for making gas, and for metallurgical and other processes. The cost of petroleum delivered wholesale in London and Liverpool is—American Ordinary 3¾d. to 4d. per gallon; Russian Ordinary 3½d. to 4d. per gallon; Scotch Shale Oil 2¼d. per gallon.

Advantages.—The first advantage of using petroleum as fuel, whether under boilers or in the cylinder of an engine, is its purity. It contains no sulphur, and is said to give off little or no smoke. If the oil is perfectly consumed, petroleum is the cleanest of all fuel. Where the oil is used as liquid fuel to evaporate water, heat is economised because, as it passes automatically into the furnace from a tank, it is not necessary to open the fire door, and the temperature of the furnace is not lowered. Petroleum is also much more convenient to store, and occupies much less space than a corresponding quantity of coal. Lastly it is of much greater heating value, as shown by the amount of water it evaporates per lb. of fuel. It has twice the evaporative power of some coal. Professor Robinson quotes figures to show that it evaporates at least 50 per cent. more steam than best Durham steam coal. Russian petroleum refuse burnt in a series of shallow troughs under ordinary boilers evaporated 14½ lbs. of water per lb. of refuse; coal burnt in the same boiler gave an evaporation of 7 to 8 lbs. water per lb. of coal. So high a result is not obtained when the astatki is sprayed. Professor Unwin tested the evaporative value of petroleum under a steam boiler, and found it to be 12·16 lbs. water (from and at 212° F.) per lb. of oil burned. The rate of evaporation was 0·75 lb. water per square foot of heating surface. He estimates the calorific value of the

petroleum he used at about 25 per cent. higher than an equal weight of Welsh coal.

Liquid Fuel.—It is on the Russian South-Eastern Railway, between Grazi and Tsaritzin, that the value of petroleum as fuel for evaporating steam in locomotives has been thoroughly tested. Mr. Urquhart, the able superintendent of the line, has by degrees replaced coal by petroleum in almost all the engines under his charge. In the oil obtained at Baku there is a residuum of 70 to 75 per cent. after the volatile naphtha and ordinary kerosene have been drawn off by distillation, and prior to its utilisation under boilers on this railway enormous quantities of this refuse were thrown away. Before 1882 the locomotives were fired with anthracite, but after various attempts Mr. Urquhart succeeded in altering the shape of the fire box and tubes to burn petroleum. There are 423 miles of railway on the Grazi-Tsaritzin line, and 143 engines are now fired with petroleum. The specific gravity of the oil used varies from 0·889 to 0·911, and its weight is 55 to 56 lbs. per cubic foot.

The tank containing the petroleum is placed for safety inside the feed-water tank in the tender. The oil is drawn from the tank through a pipe, terminating in a nozzle, and injected into the furnace. The size of the orifice has been carefully determined by experiments. A smaller tube containing steam from the boiler passes down the centre of the oil pipe; the steam and oil mingle at the mouth of the nozzle, and are injected as fine spray into the fire box. At the junction of the tube and fire box they are open to the atmosphere, and the air, having free access, is drawn by suction to the nozzle, and enters with the steam and oil. The force of the mingled blast is sufficient to break up the oil into very fine spray, which is driven against a fire brick division in the lower part of the fire box, and thus still further subdivided, before it rises into the upper part of the furnace as flame. A bridge of fire brick is now used to divide the fire box into two sections, and round and through this each jet of air, steam, and petroleum vapour has to pass. The actual arrangements of the fire box, &c., vary of course with the class of boiler used, whether marine, horizontal, or vertical. Besides the locomotives, a great many stationary boilers are fired with petroleum. It was at first found difficult to keep the oil in a proper liquid state during the severe Russian winters. A certain quantity of solar oil (one of the lighter oils obtained from petroleum) is now added to it, and steam is carried from the locomotive boiler through the oil tank to heat it, by means of a coil of pipes.

Cost of Working.—As regards the cost of working with petroleum, the best proof of its economy is the fact that from 1882, when it was first used on this railway, to 1888, it gradually and entirely superseded coal. The saving in money is stated by Mr. Urquhart to be 43 per cent. In 1882 the consumption of coal

per engine mile, including wood for lighting up, was 55·65 lbs., costing 7·64d. In 1887 30·72 lbs. of petroleum refuse were used per engine mile, costing 4·43d. The expense of repairs was also much less, owing to the absence of sulphur in the oil. Other railways in Russia are now beginning to adopt petroleum as fuel. The locomotives on the new Trans-Caspian lines are fired with it, as no other combustible is available, and the stores of liquid fuel will probably form an important factor in the Russian advance across Central Asia.

On the question of the evaporative power and heating value of petroleum as compared with coal, Mr. Urquhart speaks with authority. He estimates the heating power of petroleum refuse at 19,832 B.T.U., and of an equal weight of good English coal at 14,112 B.T.U. Theoretically, 1 lb. of petroleum refuse evaporates 17·1 lbs. of water at a pressure of 8½ atmospheres, while 1 lb. of good English coal evaporates 12 lbs. water under the same conditions. In practice he found that the petroleum used on his engines evaporated, at this pressure, 14 lbs. water per lb., or 82 per cent. of the total possible evaporation.

Petroleum on an English Railway.—Some kinds of heavy petroleum are also utilised as fuel on the Great Eastern Railway. Mr. Holden, the locomotive superintendent, finding much difficulty in getting rid of the refuse from shale oil distilleries, tar from oil gas, green oil, creosote, and other heavy residuum, has adopted a method somewhat similar to the Russian plan, for burning them under boilers instead of coal. The oil used is entirely heavy refuse, thicker and less easy to evaporate than Russian astatki. It is conveyed from the tank through a pipe, and injected into a furnace, but the air passes to the spraying nozzle through a central pipe, and steam is twice sprayed on to the petroleum before it is sufficiently volatilised to be converted into fuel. In all cases where heavy oils are broken up by injection, superheated steam is found most effectual. The injector is in three annular concentric parts. The liquid petroleum enters one passage, a jet of superheated steam passes through another, carrying with it a current of air down the central tube. Before the oil reaches the nozzle, it is broken up into spray by the steam jet. After the petroleum, steam and air are sprayed into the fire box, a separate supply of superheated steam is injected into the petroleum, and completely atomises it. The vaporised liquid strikes against brickwork in the fire box, is broken up, and forms a broad, concentrated flame. On the bars of the grate a thin layer of fuel, usually cinders mixed with chalk, is kept burning, to maintain a uniformly high temperature, to decompose the oil, and ignite the spray. Arrangements are made to fire the boilers with oil or coal, according to the price at which they can be procured. It is sometimes cheaper to burn one, sometimes the other. As with the astatki burnt on the Russian

railways, the oil is so thoroughly mixed with steam and air that there is no smoke, unless it is purposely produced by diminishing combustion. The mixture employed by Mr. Holden consists of two parts coal tar, and one part green oil, and costs generally about 1¼d. per gallon. The same system of firing locomotives with oil refuse is used on the Great Western Railway in the Argentine Republic, where there are abundant oil fields.

Petroleum for Marine Purposes.—Marine boilers have often been fired by petroleum. About 1867 experiments were made by Mr. Isherwood, of the United States Navy, on board the gunboat "Pallas," on liquid petroleum as fuel. He was convinced of its superiority to coal in heating value, convenience of storage, weight, bulk, absence of stoking, and consequent saving of manual labour. He found also that the lighter oils, which explode very easily, burn completely, and leave no deposit. Against these advantages must be set the great drawback of using petroleum to any great extent as marine fuel, namely, the danger of carrying an inflammable oil, giving off volatile gases at a low temperature, in bulk at sea. For this reason, no kinds of oil but heavy residuum and astatki are likely to be used at present for marine purposes, except on small ships. The oil tested by Isherwood was utilised in the same way as on the Russian and Great Eastern Railways—namely, injected into the furnaces, after being thoroughly mixed with steam and air. Petroleum refuse is as cheap in America as on the shores of the Caspian.

II. **Oil Gas.**—The manufacture of gas from oil differs little in principle from the process of distilling gas from coal. The oil is dropped or poured into a retort kept at a strong heat, and the vapour given off is purified, washed, and cooled in the same way as lighting gas. All oils are not equally fit for gas making. Very heavy oils, as tar or blast furnace oils, creosote, &c., though they are vaporised for a time by the application of heat, condense again under pressure, and cannot be converted into a fixed gas. The best way of utilising them is to burn them, as already described, under locomotive or other boilers. Oil of low specific gravity, as petroleum spirit, is too volatile and evaporates too readily. For making gas the best oils are the intermediate, such as Scotch shale oil, which are too heavy to be vaporised completely in an oil engine, but are found to yield a very rich gas, well adapted for the purpose of driving motors. Vegetable oils and animal grease, fat or dripping can also be used in this way. Such motors, however, worked with oil gas in the same way as a gas engine is driven with lighting or cheap gas, are not oil engines, properly so-called, and must be distinguished from them. They do not, as in true oil engines, prepare the fuel for combustion, as well as utilise it in ignition and explosion. They are in reality gas engines, the gas used being distilled from oil instead of from

coal. Nor is the economy so great as in oil motors, because heat must be applied, first to turn the oil into gas, and then to convert the gas into energy. In oil engines one application of heat suffices for both purposes, but the power generated is not so great.

Distillation of Oil Gas—The method of distilling oil does not vary much in the different systems, though it is usually necessary to modify the process slightly, to suit the oil or other refuse utilised. Thus in Alsace and in parts of France where there are deposits of bituminous schist, the crude petroleum refuse is allowed to fall in a thin stream into the retort, which is kept at a dull red heat by means of a fire beneath, and after being purified the oil gas is stored ready for use. The gas obtained has twice the calorific value of the same volume of coal gas. In another process, where a wrought-iron retort is heated to a cherry red by a furnace, the gas distilled has four times the calorific value of coal gas, and costs about 60 centimes per cubic metre. The quality of the gas depends chiefly on the temperature of the retort. In other countries various substances are successfully distilled to produce oil gas, such as linseed oil in Brazil, castor oil in Burmah, palm oil in West Africa, mutton fat in Australia and South America, and in general fatty refuse of all kinds, wherever it is found in abundance. In Great Britain oil gas is usually made from Scotch shale oil, of specific gravity 0·84 to 0·87, flashing point from 235° F. to 250° F., and yielding about 100 cubic feet of gas per gallon. The heating value of this intermediate oil is much increased, if the oil be injected into the retort by means of steam jets. The steam is decomposed by the heat; CO, a gas very rich in lighting value, is formed by the combination of the oxygen in the steam and the carbon in the oil, and deposit of solid carbon is prevented.

The first oil gas producer was introduced into England in 1815 by Mr. John Taylor, of Stratford, Essex. The oil was passed successively through two retorts, to vaporise it thoroughly. Experience has since shown that one retort, if kept steadily at a proper temperature, is sufficient to volatilise all the lighter hydrocarbons contained in the oil, and convert them into gas.

Oil Gas Producers—Mansfield.—The Mansfield oil gas apparatus is one of the oldest producers, and that most commonly used. Gas can be made in it, not only from petroleum, but from any kind of oil, fat, &c. Fig. 112 gives an external elevation of this producer. A is the receptacle containing the oil or fat, which becomes gradually heated and liquefied, if solid, by the heat from the retort below. From here the oil passes in a thin continuous stream into the siphon pipe S, where it is vaporised, and conducted through the wide tube or hood, B, to the retort, R, in which it is further decomposed, and made into a permanent gas. The retort is placed in the centre of a

cast-iron casing, C, lined with fire brick, L. Before any oil is admitted the brick lining is heated, and the retort brought to a cherry red heat, or a temperature of 1,600° to 1,800° F., by the fire F under the retort. Unless combustion is carefully adjusted by means of the damper D at the top of the furnace, regulating the discharge of the products of combustion, and the openings M below, admitting the cold air, the quality of the gas is affected. The cock through which the oil passes into the pipe S is not opened until the retort, as seen through the sight hole *p*, has been heated to a cherry red. The gases from R pass through the hood B down the stand pipe P to the hydraulic box H, where they are washed, and freed from the tarry products given off in the manufacture of gas, by forcing them through water. The hood B rests upon two sockets. O, above the retort, is filled with lead, which melts with the heat, the hood sinks into it, and an impervious joint is thus formed during the gas making process. The other socket, K, is filled with water to prevent the escape of gas unless there is any undue pressure, when it forces its way out. At V is another safety valve, in

Fig. 112.—Mansfield Oil Gas Producer.

case too much gas is produced; the tarry deposits are withdrawn through the door N. The purified gases then pass through the pipe Q to a gasholder.

Two things are necessary to make good gas in the Mansfield producer. The heat of the retort must be sufficiently intense to decompose the oil, and the stream of oil must be so regulated

that no more passes in at a time than will produce a rich gas. With intermediate oil, 1000 cubic feet of gas are made from 7 to 9½ gallons of oil, or about 100 cubic feet per gallon. When used to drive an Otto gas engine, Messrs. Crossley give the consumption in a 12 H.P. motor at 9 cubic feet of gas per I.H.P., or 10 cubic feet per B.H.P. per hour, the gas being more than twice as rich as lighting gas. The total cost of oil and fuel, with oil at 4½d. per gallon, is about 6d. per 100 cubic feet. This is much more expensive than coal gas in England, but abroad, where coal is usually dearer, power may sometimes be most cheaply obtained by an engine driven with gas made from oil or fat in a Mansfield producer. At the Melbourne Exhibition in 1888, an Otto engine was driven by gas thus generated from dripping or fat at the rate of 100 to 120 cubic feet per gallon. The flashing point of the fat was above 400° F., and it was previously liquefied by a burner.

Keith.—The Keith oil gas producer is especially adapted for oil made from Scotch shale. The principle on which the gas is made is the same as in the Mansfield producer, but the process is more rapid. The oil filters down through shallow iron troughs placed in the retort, till it reaches the lowest part, where the temperature is highest. Here it is converted into a gas and led off to the washer, and then direct to the gasholder, where it is cooled and stored. The pipes are large, and the pressure of the gas is kept low until it has passed to the holder. As it is principally intended to drive engines, it is unnecessary to purify it further. For illuminating purposes it is again passed through lime and sawdust, and after it has reached the holder, the pressure is raised by compression pumps to 150 lbs. per square inch. The gas produced, of 60 candle power, is exceedingly rich, and too powerful to use in a gas engine without altering the valves and passages. It is therefore diluted with air in an apparatus called a mixer, in the proportion of 35 parts by volume of air to 65 parts of oil gas, and is then of about the same strength as the lighting gas used in motors. It is, of course, again diluted with the proper proportion of air, when introduced into the cylinder of an engine.

The most important application of the Keith oil gas process is on the Ailsa Crag lighthouse in Scotland. Here it supplies five 8 H.P. Otto gas engines, working the air compressors for the two fog signals. There are four air-pump cylinders, each 10 inches diameter and 18-inch stroke; they are driven at a speed of 160 revolutions, and the air is compressed to 75 lbs. per square inch. The fog signals are in different parts of the island, at a considerable distance from the air compressing station. To supply power for fog signals, which are often required at a few minutes' notice, gas engines are of special value, because they can be started without delay. In this lighthouse twelve gas

retorts are used, producing 10,000 cubic feet in four hours from 100 gallons of ordinary illuminating paraffin, distilled from Scotch shale. From 20 to 30 cwt. of coal are required to heat the retorts. The four engines consume 26 cubic feet of pure oil gas per H.P. per hour, or 6·5 cubic feet for each engine. The price of the gas is 5s. 9d. per 1,000 cubic feet; total cost of working, about 1·16d. per effective H.P. per hour. The output is rather expensive, owing to the isolated position of the lighthouse, and cost of carriage of coal and oil.

Rogers.—In the oil gas made by Messrs. Rogers, of Watford, steam heated by the waste heat from the furnace is injected with the oil into the retorts. The steam is decomposed, and the oxygen contained in it combines with the carbon of the oil to form carbonic oxide, thus preventing the deposition of solid carbon to any considerable extent. In all these processes, where the oil is first turned into gas, and then used to drive a motor, more power is developed than where it is evaporated directly in the cylinder, although some heat is lost.

Pintsch.—The Pintsch oil gas system differs from those already described because the oil, being intended for illumination, is more thoroughly purified. It is introduced successively into two retorts, one above the other. The upper, into which the oil first enters through an inverted siphon, is kept at a moderate temperature; the lower retort, in which the process of evaporation is completed, is at a cherry red heat. As it enters, the oil is received on sheet-iron trays, over which it passes to the upper retort, and descends through pipes to the lower. It has now become a thick yellow vapour, in which shape it enters a hydraulic box, where it is partially washed, and thence passes to the condenser, the tar being carried off by overflow pipes to a separate tank. The gas is finally purified by forcing it through a vessel, the lower part of which is filled with water, and the upper with lime and sawdust. When cooled, it can be stored in the condenser at a pressure of about 10 atmospheres. The illuminating power of the gas produced is about 40 or 50 candles, but the pressure causes it to lose 20 per cent. of its lighting power. The best and cheapest oil for the purpose is Scotch intermediate oil, having a specific gravity of about 0·840, and yielding between 80 and 90 cubic feet of gas per gallon of oil. The price of the gas varies according to the cost of the oil, fuel, &c., from 5s. 6d. to 16s. per 1,000 cubic feet. Compressed Pintsch oil gas is now largely employed for lighting railway carriages, at a cost of about 6s. to 7s. per 1,000 cubic feet, and many railways have their own gas plants. It is also much used for lighting buoys at sea and in rivers, and is burnt in the floating lights on the Suez Canal.

CHAPTER XXI.

HISTORICAL—WORKING METHOD IN OIL ENGINES—CARBURETTED AIR.

CONTENTS.—Oil Motors—Carburators—Lothammer, Meyer, Schrab—Utilisation—Vaporisation of Oil—Early Oil Engines—Hock—Brayton—Spiel—Siemens.

Oil Motors.—Having examined the first and second methods of applying oil to produce motive power, and considered it I. as liquid fuel, and II. as a gas, we now come to the study of oil motors, properly so-called. Gas engines, though far more handy than steam, are not suitable for every purpose for which motive force is required. For small powers, where steam cannot be used, because of the complication of a boiler, nor gas, when there are no gasworks near, petroleum engines supply a want, and have undoubtedly a great future before them. It is a peculiarity of these motors that the fuel is delivered to them direct, so to speak, in its original condition. In a steam engine and boiler the water must first be evaporated over a furnace; in a gas motor the working agent must either be distilled in a retort, or produced in a generator. The fuel for a petroleum engine may be purchased almost anywhere. An oil engine is self-contained, and independent of any external adjunct, but in turning this advantage to account the difficulties of the constructor are somewhat increased. Not only must the engine be designed to utilise the working agent, and obtain mechanical energy from it, but the working agent must itself be produced, and the fuel prepared for combustion.

There are two methods, Classes III. and IV. of the divisions in the preceding chapter, by which oil may, in the cylinder of an engine, be turned into a source of energy, viz.:—

III. Light petroleum spirit, naphtha, benzoline, or carburetted air is exploded, and drives out the piston of an engine by the expansion of the gases.

IV. Ordinary lighting or intermediate oil is also used to drive an engine by explosion and expansion, after its evaporation and conversion into petroleum spray. In Class III. atmospheric air at ordinary temperature and pressure is charged with volatile spirit, in Class IV. the petroleum is pulverised and broken up into spray by a current of air, with the addition of heat.

It must not be supposed, however, that all oil engines can be rigidly classed under either of these two divisions, because of the complex nature of petroleum, and the different temperatures

at which it evaporates. In one engine, the Yarrow spirit launch, nothing is used, with due precautions, but pure and rather dangerous petroleum spirit or ether. In a few motors, as the Priestman, the oil is so thoroughly pulverised and converted into spray, that the whole is evaporated and no residuum left. There are also a large number of oil engines, evaporating more or less of the volatile constituents of the petroleum, and with a proportionally large or small refuse, according to the amount of heat applied during the process, and the specific gravity of the oil used.

Until the last few years it was believed to be impossible effectually to vaporise oil, and render it fit for combustion in an engine cylinder, except by the use of some spray-making device. The behaviour of oil in a retort was quoted to show that it must be dealt with in some complicated way, in order to evaporate it completely. It was first pointed out by Mr. Worby Beaumont, and has now been conclusively proved, that the addition of air in an engine cylinder, (which does not take place in a chemical retort), prevents the formation of oil gas and heavy residuum, and is sufficient to convert the whole of the oil into a combustible. The use of a spray maker has, therefore, been discarded in almost all engines except the Priestman, and the process of vaporising becomes simpler in each successive oil motor.

There are two methods of evaporating petroleum, both used to prepare it for driving an engine—viz., hot and cold distillation. We have seen that, the less the specific gravity of the oil, the more volatile it is. The higher the temperature to which it is exposed, the greater the evaporation, or the amount of hydrocarbons given off. It is only the light and highly inflammable spirit used in engines of Class III., which can be evaporated from petroleum without the application of heat. The heavier oils, of greater specific gravity, must always be heated, not only to vaporise the larger portion of their constituents, but to counteract the cold produced by evaporation.

III. Distillation at ordinary atmospheric temperatures is produced in the following way:—Atmospheric air is passed over light hydrocarbon oil (refined petroleum), and a volatile spirit is given off in large quantities, impregnating the air in contact with it. This carburetted air is equal in lighting and heating properties to coal gas, and, mixed with a proper proportion of ordinary air, it is sufficiently inflammable to ignite, and to do work in the cylinder of an engine by the force of the explosion. Sometimes, instead of passing the air over a layer of the oil, a current is driven through substances impregnated with the volatile spirit. The specific gravity of this petroleum spirit varies from 0·650 to 0·700, and its flashing point is generally so low that it cannot be used for commercial purposes. Motors in which it is employed ought scarcely to be called "oil engines." The working agent is simply inflammable petroleum essence, and is perhaps best dis-

tinguished by the term usually applied to it abroad—"carburetted air." The ease with which this spirit can be obtained from ordinary petroleum by merely passing air over it shows that care is necessary. An inflammable vapour generated without the application of heat, will ignite at ordinary temperatures, and cannot safely be stored. Nearly all the early petroleum motors employed this spirit as the motive power, and this is perhaps one reason why they did not come into general use. Owing to the inflammable nature of the working agent, a prejudice existed against them, which extended to all oil motors, and was not removed until the Priestman engine showed how ordinary oils could be utilised in the cylinder of a motor without danger.

Engines driven with carburetted air are also open to two objections from an economic point of view. The continued evaporation of the more volatile portions of the petroleum leaves a heavy useless residuum, difficult to get rid of. As the spirit is given off, the cold produced by evaporation rapidly reduces the temperature of the oil, and renders it less ready to part with the lighter constituents. These essences also carry off with them mineral or organic substances, which when burnt in the cylinder leave a thick deposit, and clog the working parts. Explosive gases therefore, produced by passing cold air over petroleum oil, are not suitable for use in a gas engine.

These difficulties are partly remedied by another method of obtaining carburetted air for a motor. The oil cistern or tank is placed near the cylinder, its temperature is thus raised, and the oil is agitated, in order to bring a larger surface in contact with the air. If the oil is slightly heated, not only will evaporation proceed more quickly, but less dangerous oil, having a greater specific gravity, can be used. The cost of working is also less, because volatile oils, having a specific gravity of about 0·650, are costly as well as dangerous. There is another advantage in placing the oil tank and carburating apparatus near the engine. Air which can be rapidly carburetted by bringing it in contact with petroleum essence, becomes decarburetted with equal facility, if exposed to a low temperature or pressure, or conveyed to the cylinder in long pipes. To carburate it therefore close to the engine economises the heat, and produces a more permanently inflammable gas.

Carburators.—There are many devices for producing carburetted air by passing it over petroleum spirit, but with most of them the gas obtained is only used for lighting. In America it is frequently made in the cellars of a house, as it is wanted for domestic purposes. The petroleum spirit or gasoline is stored in underground tanks, and air at ordinary temperature is pumped on to it through a pipe, and then drawn off and conveyed to the house burners. On this small scale there is little danger in employing carburetted air, but carburators above

ground cannot be used with perfect safety. In most of them the principle is the same. Air is forced either by compression or suction through or over petroleum spirit, and becomes impregnated with the essence. In the *Lothammer* carburator air at ordinary temperature is pumped into an outer reservoir, containing an inner receiver partly filled with the carburating liquid. It next passes at high pressure from the outer reservoir into tubes, which are carried down into the inner receiver below the level of the liquid. Here it is discharged through radiating horizontal pipes, and forced to pass upwards, the pressure of the air breaking up the liquid. By this process the air becomes thoroughly saturated with the volatile essence, and is then drawn off and stored. M. Lothammer claims to obtain a gas which does not lose its heating qualities, even when exposed to a temperature of $-18°$ C. on leaving the carburator. Drawings and a description of the Lothammer apparatus will be found in Chauveau.

In the *Meyer* carburator heat is employed to charge the air with petroleum essence. The oil or hydrocarbon liquid falls drop by drop into a small boiler, where it is evaporated by the heat from a burner below. The oil vapour at a high pressure next passes through an injector, where a proper proportion of air is drawn in with it, and the two are thoroughly mixed before they enter the gas holder. Production is automatic, and the bell of the gasholder is made to regulate the admission of oil to the boiler, and the size of the flame. This method is said to produce carburetted air of nearly 10,000 calories per cubic metre heating value; it is principally used for driving engines. An ingenious method of carburating air, which does not yet seem to have been applied in practice, has been proposed by M. Schrab. Hydrocarbon liquid is substituted for water in the jacket of an engine cylinder, and is heated to about 80° C. by radiation from the walls. It then passes into a vaporising chamber, through which the exhaust gases are driven. The gases compressed into the boiling liquid become charged with hydrogen, carbonic oxide, and other combustible vapours, and return to the cylinder, where they form the fresh charge, and are ignited and expanded as before. The inventor affirms that these gases only require one-sixteenth as much petroleum essence to form an explosive mixture, as would be needed if fresh air were used, and that 1 litre of gazolene per H.P. is sufficient to work his engine for 10 hours. The idea has not apparently been further developed. There are numerous other carburators, especially in France, as the Mounier, Pieplu, &c., but they are chiefly used to furnish carburetted air for illumination. Each oil motor employs a special type of carburator, or method of vaporising the oil, and these will be described later, in the account of the various engines.

Utilisation of Oil.—Professor Unwin is of opinion that the

three methods of utilising petroleum, as fuel under a boiler, as oil gas, and to carburate air, are none of them capable of any wide application, owing to the expense, the difficulties of transport, and the danger of using a highly inflammable liquid. The true oil engine of the future is probably of the fourth class, and comprises motors using and more or less completely evaporating ordinary lighting or heavy petroleum oils. Oil engines, however, are still in their infancy. If gas engines are younger and more modern than steam, and therefore have more possibilities of future development, the same applies in a still greater degree to oil engines. In some respects a greater heat efficiency, both in theory and practice, ought to be obtained from oil than from gas motors. In the latter the gas must be kept cool till it is introduced into the cylinder, and therefore, as it has hitherto been found impossible to utilise the exhaust gases, a large proportion of the heat is wasted. In an oil engine the working agent should be at a high temperature from the first. A certain amount of heat is necessary to render the oil fit for evaporation, and this heat is sometimes supplied by making the exhaust gases circulate round the oil tank or vaporiser. The air also is sometimes previously heated by the exhaust in various ways. Hence more heat is utilised, the exhaust gases are comparatively cool at discharge, and a better working cycle should be the result. Hitherto, however, the heat efficiency is found to be about the same with oil as with gas engines.

IV. In the fourth method of producing heat from oil,—namely, by evaporating ordinary petroleum, and firing it as in a gas engine,—the density of the oil used varies from 0·70 to 0·84. To ignite so heavy a liquid, and utilise the force of the explosion to drive a piston, the oil must be converted at a high temperature into an inflammable vapour, before it is admitted to the cylinder, and this is done in various ways. Frequently a blast of compressed air is forced into the petroleum, to divide it up. All oil engines have a vaporiser or hot chamber, where the petroleum, either liquid or in the form of spray, is converted into vapour. The vaporiser is usually heated by a lamp at starting, and afterwards by the exhaust gases, or by other means. The air necessary for combustion is admitted and mixed with the charge of petroleum, after the latter has become vapour. The mixture is then drawn into the cylinder, as in a gas engine, by the suction of the piston. Ignition is generally by a tube, but electric ignition is also used, and a safety or non-return valve is necessary, to prevent the flame from shooting back into the vaporiser. With these precautions ordinary lighting oil with a flashing point of from 25° C. to 50° C. may be used to generate power, as safely as gas or steam. It has not yet been adapted to any great extent for marine purposes, except for small power launch engines, because of the difficulty of carrying

an inflammable liquid at sea, but for small motors on shore, portable engines, and to propel road carriages, it is already in considerable request.

Vaporisation of Oil.—There are three ways in which oil is treated, when employed as a combustible in the cylinder of an engine. In the first, it is broken up into spray, and thoroughly mixed with air, before it passes into the cylinder, as in the Priestman engine. In the second, liquid oil is injected into compressed and heated air, and instantly vaporised, as in the Hornsby-Akroyd. The third method is to admit the oil in small quantities into a vaporiser maintained at a very high temperature, which acts as a retort, and converts the oil into gas before it reaches the cylinder, as in the Trusty and Capitaine engines. One or other of these principles is followed in almost all oil motors, to render the petroleum fit for combustion, but a different arrangement is adopted in each particular engine, for the vaporisation of the oil.

Early Oil Engines.—The earliest attempts to use petroleum to produce mechanical energy were made soon after the introduction of gas engines. At that time, however, it was considered impossible to use ordinary petroleum, of about 0·800 specific gravity, because the difficulty of evaporating it was so great. To break it up into spray by a blast of air had not been proposed. Light petroleum spirit or inflammable ether was therefore employed, and probably retarded the development of the oil engine.

Hock (1873).—About twenty years ago two engines appeared almost simultaneously, the Hock in Vienna, and the Brayton in America. In the Hock engine, the patent for which was taken out in 1873, benzoline or volatile hydrocarbon gas was used, drawn from a reservoir at the back of the horizontal cylinder. The engine was of the two-cycle, single-acting non-compressing type, with an explosion every revolution; the whole series of operations was carried out in one forward and return stroke. On one side of the cylinder was a small valve chest containing two valves, one for the admission of air, the other for the discharge of the exhaust gases, both worked by an eccentric from the main shaft. On the other side was the igniting apparatus. A little air pump, driven from the crank shaft, forced a current of air at each stroke into a small receiver filled with benzoline. The air became charged with benzoline, and a stream was directed through a nozzle against a permanent burner, placed close to an opening at the back of the cylinder. The benzoline ignited at the flame, a flap covering the admission valve was lifted by the suction of the in stroke, the flame drawn in, and the mixture in the cylinder ignited. The permanent burner was fed with petroleum spirit from the same receiver.

The motor piston having passed the inner dead point, the suction of the out stroke drew a small quantity of hydrocarbon, at atmospheric pressure, from the reservoir at the back through a nozzle into the cylinder. At the same time a flap valve was lifted, and a stream of air, also at atmospheric pressure, was admitted through another nozzle beside it. The two nozzles being set slightly inclined to each other, the air pulverised the benzoline, and broke it up into spray. As the charge was too rich to use, it was next diluted with a second supply of air from the valve chest. When the piston had passed through about half the stroke, ignition took place, as already described, the mixture being so arranged, that the richest portion lay nearest the ignition flame. The return stroke discharged the products of combustion. The centrifugal governor driven from the crank shaft acted by regulating the supply of air from the valve chest. If the speed was increased, the valve was held open longer, a larger quantity of air was admitted, and less benzoline. When the speed was reduced, and the balls of the governor fell, less air entered, the composition of the charge became richer, and the explosions more certain and stronger. This engine was popular for a time, but it was not permanently successful, on account of the inflammable nature of the petroleum spirit used. Drawings are given in Schöttler's book.

Brayton (1872).—The engine patented by Brayton, and first constructed at Exeter, United States, was introduced into England about 1876. It was a better and more practical motor than the Hock, because the oil used was of greater density, higher flashing point, and less inflammable. Brayton was the first to employ ordinary heavy petroleum and kerosene, boiling at about 150° C., instead of light spirit or essence, in the cylinder of an engine. His engine, called the "Ready Motor," was also the first, and till now the only engine of any note, to embody the principle of combustion at constant pressure, instead of at constant volume. It was originally worked with gas, and was first brought out in America; the English patent was acquired by Messrs. Simon of Nottingham, who introduced it into this country in 1878 (see p. 51). A view of the Brayton-Simon engine is given at Fig. 11. The charge of gas and air was ignited before its admission into the cylinder, entered in a state of flame, and drove the piston forward without any rise in pressure, a steady combustion being maintained behind it during one-third of the forward stroke. As Brayton found that the flame of the gas, in spite of the gauze diaphragm shutting it off from the pump cylinder, was apt to strike back, and ignite the compressed charge in it, he substituted ordinary petroleum, instead of gas, as the motive power. The specific gravity of the oil used was 0·850, and one volume of petroleum was sufficient to carburate 24 volumes of air.

The chief improvement exhibited by the Brayton engine over

the Hock was that both the air and the oil were admitted, at high pressure, into the motor cylinder from two pumps, worked from the main and the auxiliary shafts. The pressure of the injection pulverised the petroleum, and the air became thoroughly impregnated. In all oil engines hitherto constructed, the use of light petroleum spirit made it unnecessary to spray the oil. The system of breaking it up by forcing a blast of air into it rendered possible the use of heavy petroleum oil. Brayton was therefore the inventor of the first safe and practical oil engine, and in this respect his motor was the forerunner of the Priestman. Various modifications of it were brought out, some horizontal, others vertical, and one double-acting type is mentioned by Professor Witz.

As shown at the Paris Exhibition of 1878, the Brayton engine was vertical and single acting, resembling the Simon at Fig. 11, p. 52, except that the crank and distributing shaft are above the cylinder. There is an impulse every revolution. The two pistons, motor and compressor, work downwards upon a beam joined to the motor crank by a connecting-rod. Both cylinders are of the same diameter, but the stroke of the compression pump is half that of the motor piston. From the pump, part of the compressed air is delivered direct through the carburator into the motor cylinder, and part is forced into a reservoir in the base. The air here stored is intended to equalise the pressure, and to assist in starting the engine. On the other side of the motor cylinder is a small pump worked from an eccentric on the auxiliary shaft, to inject petroleum into the carburator. The different lift-valves to motor cylinder, pump and exhaust, are worked by cams from this auxiliary shaft, driven by bevel gear from the crank shaft, and revolving at the same speed. The admission cam to the working cylinder is moveable, and is shifted by the governor, in order to admit more or less of the charge, according to the speed of the engine.

Brayton Carburator.—Fig. 113 gives a view of the carburator placed at the top, just above the motor cylinder. It is in three compartments. The carburation of the air takes place in the middle division B, which is filled with felt, sponge, or other porous substance, and is separated by a layer of perforated metal plates at P from the space below, C, communicating through the opening D with the motor cylinder. The chamber C is always full of flame. Petroleum is injected from the small oil pump through pipe E, and air from the pump through F into B. The jet of air pulverises the petroleum and breaks it up into spray, which thoroughly impregnates the porous material filling the chamber B. At this moment the valve V rises, and fresh air is drawn through the pipe O into the outer chamber A. In its onward passage through B, it carries with it a portion of the volatilised petroleum, and

is ignited on reaching C. From hence it passes forward into the cylinder in a sheet of flame. There is no explosion, the pressure of combustion of the charge being sufficient to drive out the piston. Thus, as in later oil engines, air is twice applied, first to break up the petroleum and convert it into spray, and then to dilute it in the same way as the charge in a gas engine. When the piston has passed through one-third of its stroke, the valve V closes, shutting off communication with the outer air, and the ignited vapour is expanded through the remaining two-thirds of the stroke. During the return the products of combustion are discharged. As the diagrams show, the pressure in the Brayton engine is not high, and expansion is prolonged. Meanwhile the two pumps have injected a fresh charge of compressed air and petroleum into B, and by the time the piston has completed the in stroke, and before the valve V rises, the porous material filling the chamber is saturated with pulverised petroleum, ready to be carried into the cylinder at the next admission of air. To start the engine, petroleum is pumped in by hand, and compressed air admitted from the reservoir, and when the carburator is full of oil vapour, the little plug at G is withdrawn, and a lighted match applied; the mixture ignites, and the piston begins to work.

Fig. 113.—Brayton Carburator. 1878.

The Brayton engine is constructed on the same principle as the Davy safety lamp, namely, that of preventing back ignition by the use of a wire gauze, or perforated metal plates. It was found that, when heavy petroleum was used, the flame did not shoot back, though with compressed gas, accidents were of frequent occurrence. Combustion in the chamber C is maintained constant by the compressed air injected at F, and the engine is said to work with extreme regularity. The change introduced by Brayton seems to show that ordinary petroleum is, under certain circumstances, not so inflammable as lighting gas, but as used by him it had one great disadvantage. The petroleum vapour

deposited much carbon and soot in the passages, ports, &c., and the engine required frequent cleaning.

Trials.—A careful trial of a 5 H.P. American Brayton petroleum engine was made at Glasgow by Mr. Dugald Clerk in 1878. The mean pressure was 30·2 lbs. per square inch, diameter of cylinder 8 inches, length of stroke 12 inches. The engine made 201 revolutions per minute, and the consumption of petroleum was 2·16 lbs. per I.H.P. per hour. Much of the total power developed was absorbed in driving the air and petroleum pumps, or in other words there was a good deal of friction. During the trial the engine indicated 9·5 H.P. in the motor cylinder. Of this the pump absorbed 4·1 H.P., therefore the available H.P. was only 5·4. Only 6 per cent. of the total heat generated was utilised. The results show a much lower efficiency than might have been expected, owing to faulty construction. Fig. 114 gives a diagram taken from the motor cylinder during the trial, in which the prolonged combustion obtained with ignition at constant pressure is noticeable.

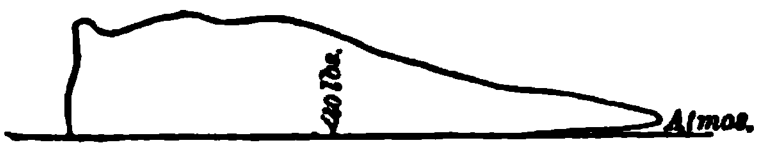


Fig. 114.—Brayton Petroleum Engine —Indicator Diagram. 1878.

Spiel (1883).—Both the two motors described above were brought out before the success of the Otto engine had fully established the superiority of the four-cycle type. In the next oil engine, patented by Spiel, and made in England by Messrs. Shirlaw & Co., Birmingham, the Beau de Rochas four-cycle is introduced, and the engine resembles the Otto in many respects. It has the drawback of using inflammable petroleum spirit of 0·700 or 0·730 specific gravity, instead of the safer heavy petroleum. Being easily volatilised, this spirit does not require so complicated a process to convert it into spray as in engines employing oil of greater density, and the method of introducing it in the Spiel is simple. The engine is horizontal and single-acting, standing on a solid base, with the reservoir of oil above. The organs of admission, distribution, and exhaust are worked from an auxiliary shaft, geared from the main shaft in the usual way. The exhaust is opened, as in the Otto, by a cam and levers from this shaft, and ignition is by a flame carried in a slide valve, working at the back of the cylinder; the Spiel is probably the only oil engine firing the charge in this way. A portion of the compressed charge of oil and air in the cylinder passes through a grooved passage to a chamber in the slide valve which, as the slide is moved by a cam on the auxiliary shaft, is brought opposite a permanent flame in the valve cover, and fired. A spring effects the return movement of the slide valve, when released by the cam, and the lighted mixture is brought in line with the cylinder port, when the remainder of the charge is fired. The pressures

of the charge in the cylinder, and of the flame in the ignition port are equalised, as in the Otto engine, by means of a small passage connecting them.

The benzoline is drawn from the reservoir and injected into the cylinder by a small pump, the piston of which is worked by a cam, lever, and spring from the auxiliary shaft. The air-admission valve is also in connection with a crosshead attached to this pump. At the bottom of the pump is a double-seated horizontal lift valve, usually held open by a spring, in which position it communicates freely with the oil reservoir above. When the plunger pump is driven down, carrying with it the crosshead, the air valve is first lifted, and air enters a mixing chamber at the back of the cylinder. As the piston continues to descend, the horizontal valve is closed, and a passage opened from the pump into the mixing chamber. The pump sends a jet of petroleum spirit into the air, and in its passage it is broken into spray by striking against a projection. Thus the out (admission) stroke of the motor piston sucks into the cylinder a stream of air mixed with petroleum spray. The engine has a ball governor which, if the speed be too great, interposes a small projection between the valve-rod of the pump and the levers working it. The two become locked and cannot move, and the valve remains open, admitting air only to the cylinder, until the projection falls back, and the speed is reduced.

Drawings of this engine are given by Robinson and Schöttler. Fig. 115 shows an indicator diagram of a Spiel oil engine when making 180 revolutions a minute. The consumption of oil, when this diagram was taken, was about 1 pint per B.H.P. per hour. In another 14 B.H.P. Spiel engine having a cylinder diameter of 9½ inches, with 18 inches stroke, and making 160 revolutions per minute, the consumption of naphtha was 0·81 lb. per B.H.P. per hour, and the cost of working 0·84d. per B.H.P. per hour.

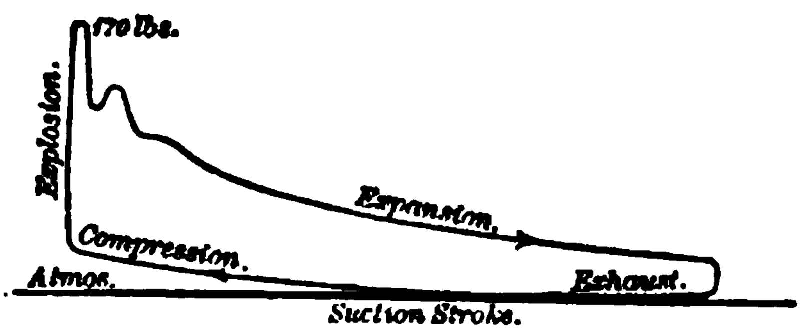


Fig. 115.—Spiel Oil Engine—Indicator Diagram.

The specific gravity of the oil used was about 0·725. It is contended by the English makers of the Spiel engine that, in spite of the difficulties of storing and transporting naphtha, owing to its inflammable nature, it is greatly superior to heavy oils for producing motive power. Some interesting experiments were made with a small model engine, running at over 500 revolutions per minute, in which the Beau de Rochas cycle, comprising the operations of admission, compression, explosion plus expansion, and exhaust were carried out four times in a second. In another

experiment it was found possible, with an initial pressure of over 300 lbs. per square inch, to remove the ignition flame, and obtain regular spontaneous combustion of the charge. Some hundreds of these engines are said to be at work.

Siemens (1861).—No account of internal combustion engines would be complete, without a mention of the motors designed and patented by Sir William Siemens. In 1860 he first devoted his attention to the subject, and from that time till 1881 he brought forward various engines, all intended to illustrate the principle of utilising the waste heat of the exhaust gases, by passing them through a regenerator before discharge. The incoming mixture entered the cylinder through the same regenerator. This idea of a regenerator in heat motors originated with Dr. Robert Stirling, a Scotch minister, in 1827, but it has hitherto been found impossible to apply it in practice, except in the case of air engines, though in metallurgy and other manufactures it is largely used.

Sir William Siemens made many alterations and improvements in the heat engines he designed. In one he proposed to add a gas generator, producing water gas by the passage of steam and hot air under pressure through incandescent fuel. The gas thus made was pumped into a reservoir, and from thence into four cylinders, each serving to charge the next through a regenerator formed of layers of metallic gauze. As the gas entered each cylinder it was ignited, and the burning gases expanded at constant pressure. This engine was not worked; difficulties would doubtless have arisen in practice from the impossibility of producing water gas continuously, and the inventor afterwards turned his attention with more success to the generation of this gas for metallurgy. From 1846 to 1881 Sir W. Siemens took out a series of patents for internally fired engines. The last, shown at Fig. 116, designed not long before his death, exhibits his matured views on the subject. Strictly speaking, it is neither a gas nor an oil engine, but both combined, the gas used as the working agent being mixed with light petroleum spirit, to make it ignite more readily. The engine which, like the Brayton, exhibits the principle of combustion at constant pressure, stands really in a separate class as a "regenerative" engine, and although never worked, it is valuable as indicating possibly on what lines the heat engine of the future may be improved.

Siemens' Regenerative Engine (1881).—Fig. 116 shows a sectional elevation of the Siemens' Regenerative Engine. There are two motor cylinders, A and A_1, working vertically through the connecting-rods C and C_1, upon the crank shaft K at an angle of 180° apart. The pistons are solid, and lined on their upper face with fire-clay, to protect them from the heat. The cylinders are practically divided into two parts. The lower in each has a water cooling jacket, W, the upper part is lined with fire-clay,

or other non-conducting material. The differential pistons compress the mixture on one face during the down stroke, while the explosive gases are expanded on the other. At the top of each cylinder are the regenerators R and R_1, consisting of thin sheets of metallic gauze. All the valves for admission, distribution, and exhaust are contained in a revolving cylindrical valve F, worked from the crank shaft by equal bevel wheels G. The exhaust E is at the top, above the revolving valve, through

Fig. 116.—Siemens' Regenerative Engine.

which a passage at p_1 is opened to it alternately from either cylinder. Gas and air, mixed in the ordinary proportions, are admitted through the pipes m and n, and ports p, opened by the rotatory movement of the valve, to the lower part of either cylinder, during one revolution of the cylindrical valve. The suction of the up stroke draws them in, the down stroke compresses them into a reservoir at the side. From here the compressed mixture passes to the upper part of the cylinders, through the regenerator and the ports p_2. The products of combustion discharged on the upper face of the piston by the up stroke are forced through the regenerator on their way to the atmosphere,

and some of their surplus heat is stored up in it. As the fresh charge enters, drawn in by the vacuum produced by the expulsion of the exhaust gases, light hydrocarbon oil is dropped on to it from the oil tank O above. Part of the mixture of oil, lighting gas and air, heated already by contact with the regenerator, is fired by an electric spark within the cylinder, the dynamo of which is driven from the main shaft. The remainder of the charge is immediately kindled, and flows forward as flame into the cylinder, the flame being prevented from spreading back into the reservoir by the gauze diaphragm of the regenerator. The piston is driven down by the expansion of the gases, and compresses below it a fresh charge into the reservoir; during the up stroke the cylindrical valve opens communication with the exhaust. The differential pistons are deep, and the parts in contact with the cylinder walls touch only the cooler jacketed portion.

Two ingenious and economical ideas are embodied in this engine. Some of the heat of combustion is stored in the regenerator, and imparted to the fresh charge, and inflammable oil is used to mix with the gas, and render it easier to ignite. Neither of these innovations has hitherto been applied to any extent, in practice, to gas or oil engines. This regenerative engine of 1881, however, may be considered as illustrating Sir William Siemens' latest ideas upon heat motors. It exhibits the outcome of the mature study of a man of scientific genius, and the direction in which he thought the problem of heat engine efficiency should be solved.

CHAPTER XXII.

THE PRIESTMAN OIL ENGINE AND YARROW SPIRIT LAUNCH.

CONTENTS.—Requisites of Oil Engines—The Priestman—Spray Maker—Vaporiser—Governor—Applications—Trials—Petroleum Spirit—Evaporative Power—Zephyr Spirit Launch.

IF Otto can claim the honour of having made the gas engine a practical working success, after the efforts of Lenoir, Hugon, and others, the same credit belongs to Messrs. Priestman as

regards oil engines. Long before the introduction of their motor into this country, oil engines had been designed and worked, but there was a prejudice against them, because of the inflammable petroleum spirit with which they were chiefly driven. The Brayton, the only engine using non-explosive petroleum, had never become popular, owing probably to the imperfections in its cycle, its extravagant consumption of oil, and low mechanical efficiency. Whatever the cause, oil engines were scarcely known or used until the appearance of the Priestman in 1888. About this time Messrs. Priestman acquired Etève's patent, and their oil motor was introduced at the Nottingham Agricultural Show in the same year.

Requisites of Oil Engines.—In any engine intended to supply the deficiencies, and remedy the drawbacks of gas or steam, the following points must be considered. It should be—I. Self-contained, having everything requisite for its efficient working for a certain length of time. II. Safe and simple, using as the working agent a combustible which is neither difficult to procure, nor dangerous to transport. III. Easy to handle, so that any ordinary unskilled workman can drive it. This is advisable, because these engines are frequently placed in the hands of labourers without any knowledge of machinery. IV. Compact, and easily transported from place to place. V. Economical in working.

Priestman.—This oil engine uses almost any kind of heavy petroleum, but it is not suitable for light volatile spirit. It works best with common petroleum, having a specific gravity of 0·800, and flashing point 100° F., but it may also be driven with heavy Scotch paraffin, of 0·820 specific gravity, and flashing point 150° F. Even common creosote of still lower density is available, but there are practical difficulties in the way of using it. Of course, the heavier the oil the thicker will be the residuum, and the more carbon is deposited inside the engine, the oftener it must be cleaned. Nor can these very heavy oils be properly treated in an engine cylinder, by raising the temperature. If the oil is too much heated, it is converted into oil gas instead of vaporised spray, and tarry deposits accumulate in the working parts. The proper temperature of the charge of oil vapour and air on entering the cylinder has been determined by experiments at from 170° to 300° F., according to the size of engine. The proportions are 191 cubic feet of air to ·015 cubic inch of oil vapour for a 1 H.P. engine.

Fig. 117 gives an elevation, and Fig. 118 a sectional view of the cylinder, water jacket, and valves of the Priestman oil engine. Both drawings, as well as several of the following details, are taken from Professor Unwin's paper in the *Proceedings of the Institution of Civil Engineers*, vol. cix., 1892. The horizontal

Fig. 117.—Priestman Oil Engine. 1888.

motor cylinder, A, is divided from the compression space, C, the proportional volumes of the two being—clearance or compression, 86 cubic inches; volume described by the piston, 191 cubic inches, for a 1 H.P. nominal engine. The piston P works on to the crank shaft through a connecting-rod. At the back of the cylinder are two valves, inlet and exhaust, as shown in the drawing, Fig. 118. The exhaust is worked by an eccentric, *k*, on the auxiliary shaft, revolving at half the speed

Fig. 118.—Priestman Oil Engine.

of the crank shaft, to which it is geared by wheels in the usual proportion. In the Priestman, as in most other oil engines, ordinary lift valves are used, of a simple type. Unless almost perfect combustion is obtained, there is much more deposit than in gas engines. The simpler the valves, the less liable they are to become clogged.

Spray Maker.—The most important parts of the engine are the vaporiser and spray maker, shown below the cylinder (Fig. 117). The oil tank in Fig. 117 is under the crank shaft, and when full, is sufficient to last for two or three days. A glass gauge shows the level of oil. A small air pump, J, is worked by the eccentric *k*, which also drives the exhaust valve. The air to supply this pump is filtered through gauze and cotton wool, and is then compressed into the oil tank at a pressure of 8 to 15 lbs. per square inch above atmosphere. This pressure forces two streams of oil and air into the spray maker S, from whence they are injected into the vaporiser. The oil is drawn from the bottom of the tank, the compressed air from the top, above the level of the oil, and both pass out through a six-way cock. When this cock is set upright, the supply of oil and air to the spray maker is cut off; when the cock is turned to the

right they are admitted, and when set to the left they pass to a small lamp below the vaporiser, used to heat it when starting the engine.

The spray maker is one of the most ingenious parts of the motor. The two streams of oil and air are injected into the vaporiser through two concentric nozzles, as seen at Fig. 119. The pulverisation of the oil and its complete mixture with the air depend on the shape of the nozzles, and their exact form has only been determined after numerous experiments by Messrs. Priestman. Fig. 119 shows the latest type. The oil passes through the central tube in a small stream, and on being ejected from the mouth of the nozzle, spreads out in a fan shape. The annular air nozzle surrounds the central oil orifice, and the air is turned back with considerable force to meet the issuing oil at more than a right angle, the result being that both are violently driven out in a spray as fine as is required. Fig. 120 shows the spray maker at its entry into the vaporiser, the method of regulating the supply by the governor, and of admitting the air necessary for the dilution of the charge.

Engine—Spray Maker.

The oil and air from the spray maker enter at the pressure of the air pump. At the same time the in stroke of the motor piston lifts the non-return valve G, and draws into the vaporiser a supply of air from outside through the throttle valve F. This auxiliary charge enters round the oil and air admitted from the spray maker, and passes through a number of fine holes, *d d*, in the circular air passage of the vaporiser *b b*, and a filtering layer of cotton wool. The sudden inrush of fresh air sweeps forward the oil and air with it into the cylinder.

Fig. 120.—Priestman Oil Engine—Vaporiser.

Vaporiser.—The vaporiser is divided into two parts. In the first the oil and compressed air are mixed with, and broken up by, the air admitted through F; in the second the charge is completely vaporised by the heat from the exhaust gases which

at a temperature of about 600° F., are led through pipe H, Fig. 117, round the vaporising chamber, before being allowed to escape into the atmosphere. Thus there are two admissions of air—one to the spray maker under pressure from the oil tank, the second at atmospheric pressure to the vaporiser through F. In each case the oil is sprayed, and is thus twice pulverised before its actual vaporisation by heat begins. Unless the heat from the vaporiser were also applied to the oil spray, it would condense and separate from the air, before reaching the cylinder. The vaporiser is contained in the frame of the engine, under the cylinder, as seen at Fig. 117.

Governor.—The speed of the engine is regulated by means of the spindle S above the throttle valve. It contains a small V-shaped opening at *f*, through which the oil is admitted from the tank to the spray maker, and the wing of the valve F is keyed to the lower part of the same spindle. The size of the sharp end of the V, which is presented to the passage of the oil, can be exactly regulated to admit a given quantity. If the speed is too great, the centrifugal governor, which is connected to the spindle by levers, drives it down, and partly contracts the opening *f* admitting the oil from the tank. At the same time it acts upon the throttle valve, and reduces the quantity of outer air passing to the vaporiser. Thus the governor acts by diminishing the strength of the explosions, not by cutting them out altogether, and the proportions of oil and air are always the same per stroke. As no explosions are ever missed, the engine works with great regularity.

The charge, after being thus converted into spray and completely volatilised, passes through the automatic admission valve *n*, Fig. 118, to the back of the cylinder. Here the usual series of operations carried out in internal combustion engines of the four-cycle type, takes place. The first out stroke draws in the air through the throttle valve F; the charge is then mixed in the vaporiser, passes through into the cylinder, and the next back stroke compresses it into the space C. As the inner dead point is reached, the mixture is fired by the electric spark, the explosion drives out the piston, and during the next back stroke, the exhaust gases are discharged through the valve *e*, opened by the eccentric, into the jacket round the vaporiser, and thence to the atmosphere.

Ignition.—The electric spark for firing the charge is generated in a battery shown to the left in Fig. 117. Many oil engines use this method of ignition, and it has certain advantages over the hot tube in this class of motor, being rather safer. In the Priestman engine the electric spark is produced in the igniting plug *i*, inside the compression space, Fig. 118. Two platinum wires are conducted from the battery to this plug, where they are insulated in porcelain tubes; contact is estab-

lished at the right moment by a projection on the eccentric rod, and an intermittent spark is produced. In some of the latest motors tube ignition is also used.

The shaft driving eccentric *k* has three functions to perform. It causes the electric ignition of the charge; it works the valve *e* to open the exhaust, and it drives the small air pump J, through which the oil and air are sent from the tank to the spray maker. A small hand pump, seen in Fig. 117 at *h*, is used to pump air into the oil tank, before the engine is at work. To start, all that is necessary is to work the handle of the pump, and to turn the six-way cock, that a supply of oil from the tank may reach the lamp below the vaporiser. When the lamp is lit, a few turns by hand are given to the flywheel, to draw a charge into the cylinder, the electric current is switched on, and the engine begins to work. The oil tank and vaporiser are easily accessible through the opening in the frame.

Although the pressure with petroleum vapour rises more rapidly than with gas, the curve of pressures, shown by the indicator diagram of the Priestman engine, does not rise as high as in gas motors, owing partly to the larger compression space. One of the advantages of the engine is that it requires no lubrication. A small portion of the oil is condensed during the compression stroke, and deposited upon the inner surfaces of the cylinder. This oil is never burnt, but forms a layer of grease, and effectually lubricates the engine, no other oiling in the cylinder being needed. As the fuel used is heavy mineral oil, it is not inflammable. Some interesting experiments to prove this have been made by Professor Robinson, who exhibited an engine before the Society of Arts in May, 1891, in which the air was shut off from the vaporiser, and oil injected alone. A lighted match held to this oil jet would not ignite, but it was readily fired as soon as the air was again admitted, to divide and break it up.

Applications.—Although only brought out in 1888, the Priestman engine has already been applied to many purposes. The first portable oil engine of 6 H.P. was exhibited at the Jubilee Meeting of the Agricultural Society in 1889. In this and similar engines, the motor is made complete in itself by the addition of a tank, the water from which is circulated in the cylinder jacket by a pump, driven by an eccentric on the same shaft as the exhaust valve eccentric. As a portable locomotive engine to replace steam, the Priestman has already been found of great value. The small bulk of oil and its great heating value make it suitable for marine work, when the danger of storing is minimised by using heavy oil. A vertical double cylinder 5 H.P. engine of this type has been fitted up on board a steam launch. It runs at 250 revolutions a minute, has a cylinder diameter of 7 inches, with 7 inch stroke. The construction and working are similar to those of the horizontal single cylinder

motor already described, except that with two cylinders an explosion every revolution is obtained. The engine can be reversed or stopped by a hand wheel acting on the main driving shaft, and is very easily worked. Hitherto these and other types of Priestman engines have only been made for small powers, but larger sizes will no doubt be produced in time. They are also used as motive power for barges, of which there are two on the Manchester Ship Canal, driven by a 10 H.P. Priestman oil engine. The fog signals on the Point of Ayr and Corsewall lighthouse stations are worked by three 5 H.P. engines, compressing the air to 40 lbs. per square inch. Each engine uses 6 pints of oil per hour. Another installation is at Oxö in Norway, where an 11 H.P. engine compresses air to 60 lbs. per square inch. The oil used is of 0·82 density, and the consumption 11 lbs. per hour. See also the Priestman engine in the chapter on Practical Applications.

Trials.—Several excellent trials have already been made on this engine, chiefly by Professor Unwin. In 1889 he tested at the Agricultural Show at Plymouth a 5 H.P. horizontal Priest-

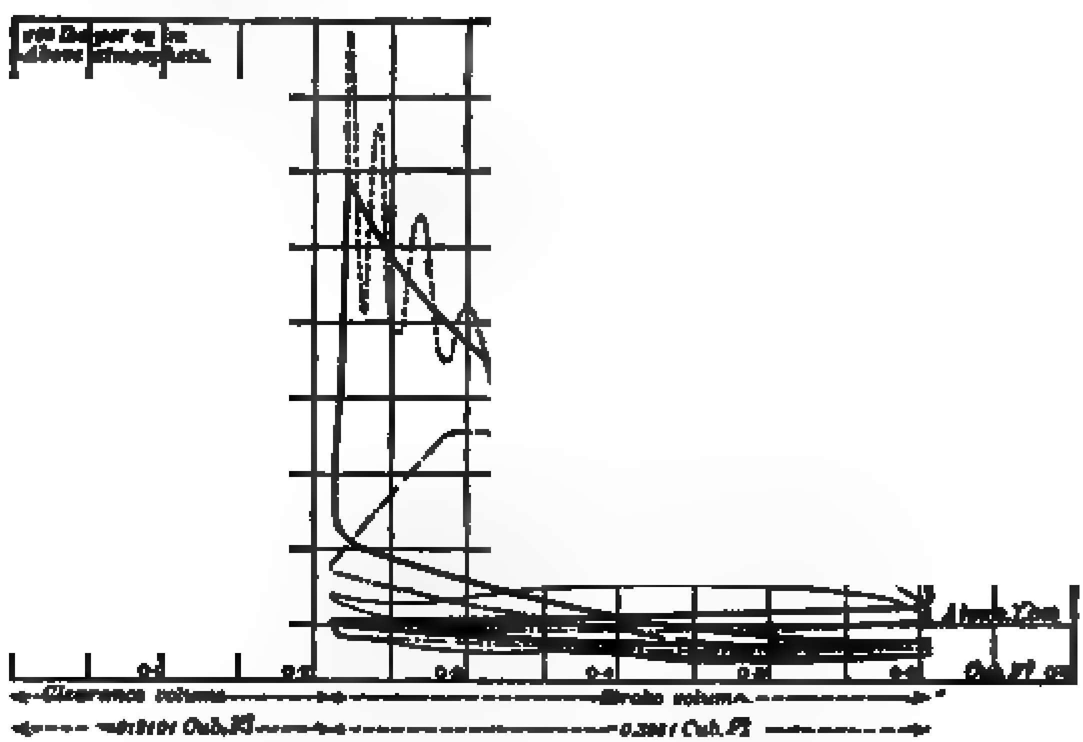


Fig. 121.—Priestman Oil Engine—Indicator Diagram.

man motor of the newest type, with 8½-inch cylinder and 12-inch stroke. Five trials were made with two kinds of oil, and every care was taken to ensure accurate results. In the first test an American oil, "Royal Daylight," was used, of 0·793 density, flashing point 77° F., and heating value about 19,700 B.T.U. per lb. The four other trials were made with Russian oil, of density 0·822, flashing point 86° F., and calorimetric value taken at 19,500 B.T.U. per lb. Fig. 121 gives a diagram taken during

the trials with Russian oil. In trials at full power the following results were obtained:—

RESULTS OF TRIAL BY PROFESSOR UNWIN ON A 5 H.P. PRIESTMAN ENGINE.

Name of Oil.	No. of Revolutions per Minute.	Mean Efficient Pressure Lbs. per Sq. Inch.	B. H.P.	I. H.P.	Mechanical Efficiency.	Oil Used per B.H.P. hour.	Oil Used per I.H.P. hour.
						Lb.	Lb.
American "Daylight," . .	204	53·20	7·72	9·36	0·82	0·84	0·69
Russian, . .	207	41·38	6·76	7·40	0·91	0·94	0·86

The heat expenditure was as follows:—Heat utilised, 16·12 per cent.; carried away in jacket water, 47·54 per cent.; in exhaust gases, 26·72 per cent.; lost by radiation and unaccounted for, 9·61 per cent. The engine was examined at the end of the trials, and found to be perfectly clean and free from soot or deposit, and the points of the electric wires were not coated with carbon.

Another trial was carried out on a 5 H.P. Priestman engine by Professor Unwin at Hull in December, 1891. The same oils were used as before—namely, Russolene and American Daylight—and tests were made, as in the other trials, with the engine running at full power, half power, and light. The trials with full load lasted nearly three hours. With Russian oil the mean speed was 208 revolutions per minute, mean pressure 41·38 lbs. per square inch, B.H.P. 6·76, I.H.P. 7·40, and the mechanical efficiency 0·91. The consumption of oil was 0·94 lb. per B.H.P., and 0·86 lb. per I.H.P. per hour. With the American oil slightly higher results were obtained. Details of these experiments will be found in the table of tests. Two trials at full and half power were made on a semi-portable 4½ nom. Priestman engine, by Professor Unwin and Mr. Pidgeon, at the Plymouth Agricultural Show in 1890. They differ very little from those already given, except that Broxbourne Lighthouse oil was used, of 0·810 density, and having a heating value of about 19,000 T.U. per lb. In the full power trial, the engine indicated 5·24 H.P., B.H.P. 4·49, cylinder diameter 8·5 inches, and 12 inch stroke. The mean pressure was 33·96 lbs. per square inch, consumption of oil 1·06 lb. per I.H.P. and 1·24 lb. per B.H.P. per hour. In all these trials the amount of heat supplied, and the different items of heat expenditure were carefully noted. Full particulars will be found in Professor Unwin's paper already quoted.

Another trial was carried out in 1890 by Mr. W. T. Douglass on a nom. 25 H.P. double-cylinder Priestman engine, driving an electric plant. The B.H.P. was 25·5, and the oil consumed per

B.H.P. per hour 0·88 pint. The progressive decrease in the oil consumption per H.P. in these engines, as shown yearly at the Royal Agricultural Society's meetings, is striking. In 1888 1·73 lb. of oil was required per B.H.P. per hour, in 1889 1·42 lb. At Plymouth the consumption was 1·24 lb., and in the latest trials by Professor Unwin in 1891 0·94 lb. per B.H.P. per hour. These results obtained at Agricultural Shows are satisfactory, because the advantage of this motor is chiefly as an agricultural portable engine, in fields and other places where gas and steam are not available.

American Type.—The engine has been taken up by a firm in America, where oil is very cheap, and there is a great demand for machinery for light work and electric illumination. The type there made resembles the straight line steam engine of Professor Sweet. Professor E. Thompson of America uses pure silver igniter electrodes, in lieu of platinum, as in the English engines. He considers them better, and the wires do not get blackened or coated. These silver contacts have been at work for several weeks without cleaning. His oil engine is started with gas, which is more convenient than oil for the lamp, and it runs at about 260 revolutions per minute. Another American authority using the Priestman engine had trouble with the internal passages and back of the cylinder, which became choked with soot, until pure air, instead of air not filtered, was admitted. The engine in this case was used for pumping water from a mine.

Up to the present time Messrs. Priestman make their engines horizontal in sizes from 1 to 27 B.H.P., vertical from 2 to 65 B.H.P. The larger sizes are with two cylinders side by side. The horizontal engines run at from 300 revolutions for smaller sizes, up to 160 revolutions per minute for the largest, vertical engines from 350 to 190 revolutions. The marine type is made vertical only in five sizes, from 2 to 65 B.H.P., with two or four cylinders. The average piston speed is about 400 feet per minute.

Zephyr Spirit Launch.—The Yarrow "Zephyr" spirit launch stands in a different category to all other oil engines, because it is the only motor using pure and highly volatile petroleum spirit, having a density of 0·68, and evaporated in the same way as steam. Sometimes the spirit is also used as the fuel. Its evaporative power, and therefore its heating value, is not so great as ordinary kerosene, about 12 per cent. less, but it has a higher pressure for a given temperature than steam, as shown by Professor Robinson's tests. At a temperature of 155° F. it has a pressure of 10 lbs. per square inch. At 212° F. (the temperature of boiling water) its pressure is 40 lbs. per square inch, while at 300° F., with steam equal to 50 lbs. pressure per square inch, petroleum spirit has a pressure of about 115 lbs. It is easily evaporated,

and may be cooled without condensing to a temperature of 130° F. Thus the range of temperature is greater, for the same pressures, with petroleum spirit than with steam, and since efficiency depends theoretically upon this range, more work should be obtained under similar conditions.

The following table exhibits the results of tests undertaken by Messrs. Yarrow, to determine the relative power of steam and of petroleum spirit, when evaporated in a boiler. The fuel used under the boiler in both cases was gas, the consumption of which was measured by a meter.

TABLE OF COMPARATIVE WORKING RESULTS OF STEAM AND PETROLEUM SPIRIT.

Boiler Experiment.	Steam Evaporated.	Spirit Evaporated.
Gas consumption in cubic feet per hour, . .	82·20	83·48
Mean pressure of spirit in coil (lbs. per sq. inch),	...	55·80
,, speed—revolutions per minute, . .	312·6	552·2
,, pressure in boiler (lbs.), . . .	38	30
Work obtained on brake in ft.-lbs. per minute,	2524	4722
Work in cylinder ,, ,, ,,	5199	11975

Evaporation of Petroleum Spirit.—As petroleum spirit evaporates at a lower temperature than steam, less heat is put into it to raise it to the same pressure; in other words, if the same amount of heat be applied to it as to steam, a much higher pressure and more work are produced. But as less heat is required to evaporate it, less heat is withdrawn in the exhaust; the quantities of heat both imparted and abstracted are smaller than with steam, for a given amount of work. At atmospheric pressure nine times as much spirit as water will be evaporated by the same amount of heat, but the spirit being very volatile, it does not increase as much in volume, and only expands to one-fifth the volume of steam. As a working agent petroleum vapour turns more heat to account than steam; the one serious drawback is its inflammable nature, and difficulty of storage.

Zephyr Launch.—In the "Zephyr" launch, the spirit is introduced into a spiral coil enclosed within a casing of non-conducting material, called the vapour generator, to which heat is applied. In its passage through the coil the spirit is evaporated, and passing into the cylinder drives the piston forward by its pressure. The exhaust products are discharged by the action of the engine into two cooling pipes, where they are liquefied and forced back to the supply tank, an air-tight copper vessel in the bow of the ship. Thus the same spirit is used over and over again, with very little waste, and the working principle and action are similar to those of a surface condensing steam engine.

The risk of explosion from the inflammable spirit is also greatly reduced, since it passes through a complete closed cycle of operations, and is never brought in contact with the external air. The danger is also avoided of storing a large quantity of petroleum spirit; a small amount is sufficient, if used continuously in this way, to produce power for many hours. A small "Zephyr" launch, 36 feet by 6, running at 8 miles an hour, can carry fuel enough for 200 miles. The action of the engine is first utilised as a pump, to force the spirit from the tank to the vaporising coil, and then to drive the exhaust vapour back to the tank.

The process of heating the spirit, or generating the vapour in the copper coil, presents greater difficulties. There are two ways of obtaining this heat. The simplest method is to use part of the petroleum spirit as fuel, as well as working agent. Sometimes it is allowed to pass through a valve to a ring gas burner under the coil, ignited in the usual way, and the flame evaporates the spirit above. A constant supply being maintained, with a proper proportion of air, the flame burns steadily, and the heat is continuously generated. This arrangement has the great disadvantage of requiring the storage of a large quantity of the dangerous spirit to feed the burner, although in the coil itself only a comparatively small portion is needed, to replace the loss by leakage. A much better plan, and that generally adopted, is to use ordinary heavy petroleum, which can be stored without danger, to heat the spirit. A small air-pump driven by the engine forces air into the oil tank, and a mixture of oil vapour and air is injected as spray into the fire box or furnace beneath the coil, in the same way that liquid fuel is broken up, injected and burnt under a locomotive boiler. After being completely vaporised by the heat, it is mixed with more air, and burns with a continuous flame like a Bunsen burner. With this method there is little risk of explosion, but a separate tank is required for the mineral oil, and power to drive the air-pump, diminishing slightly the total useful work of the engine.

In the Zephyr spirit launch the engine and spirit generator are carried in the stern of the boat, and the spirit supply in the bow, to balance the vessel, leaving the centre free for goods and passengers. The machinery is very light, and the engine, tank, &c., weigh only 1 ton in a boat 36 feet long. This class of engine is specially adapted for small launches and torpedo boats, but is unsuitable for large powers or great speeds. It can easily be started in from two to five minutes after lighting the burner, and like other vessels driven by petroleum, the Zephyr spirit launch is smokeless. The consumption of fuel for burning is about one-third of a gallon per H.P. per hour.

CHAPTER XXIII.

OTHER BRITISH OIL ENGINES.

THE Priestman oil engine is one of the few motors adapted for driving only with oil. Many petroleum engines were originally constructed to use gas as the motive power, and the oil vaporising apparatus was added afterwards. Practically all oil motors employ the usual gas engine cycle, the series of operations proposed by Beau de Rochas and adopted by Otto, comprised in four strokes of the piston, with one explosion every two revolutions. Excellent results are obtained with this cycle, and as a rule the engines run at a higher speed than gas motors. The action and method of utilising the power is the same as has already been described, the difference consists in the treatment of the petroleum. In no two motors is the process precisely the same, though in all the oil is broken up by the addition of air, and vaporised by applying heat. The following classification, given in *The Engineer*, June 24, 1892, of the methods by which the oil is evaporated, may be found useful:—

Classification.

Spray maker.	1. Engines in which the oil, before entering the cylinder, is converted first into oil spray, forming an oil shower, and next into vapour in a hot chamber.
No Spray maker.	2. Engines in which the liquid oil is injected into a prolongation of the engine cylinder, a hot cartridge chamber or combustion space, where it is converted into vapour or gas. 3. Engines in which the oil is converted into vapour or gas in a chamber contiguous to the cylinder, and communicating with it by a valve. 4. Engines in which the oil is converted into vapour or gas in a separate chamber, heated apart from the cylinder.

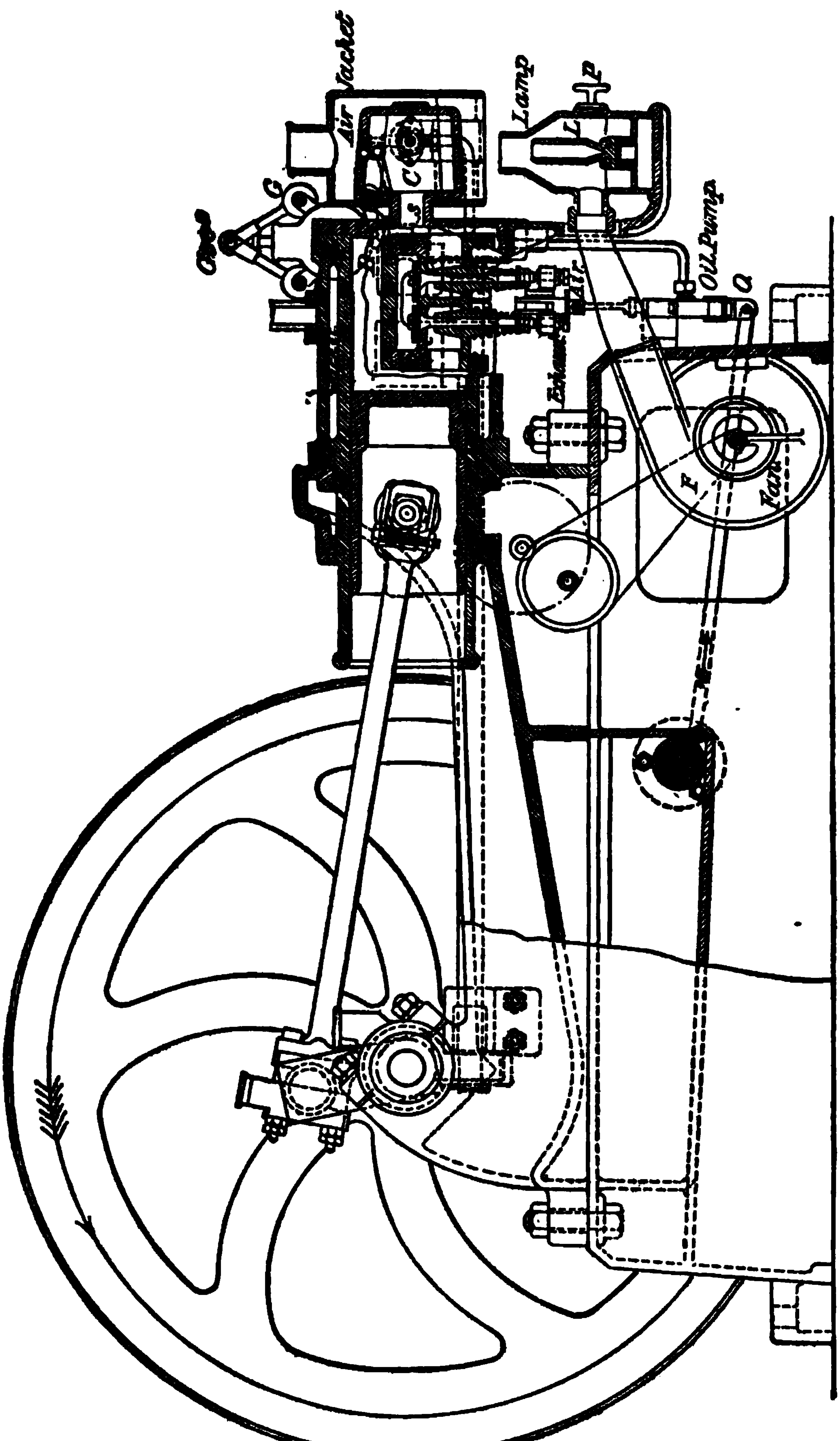


Fig. 122.—Hornsby-Akroyd Engine—Sectional Elevation. 1892.

The charge thus prepared for use is fired in one of the three following ways:—

1. By electricity.
2. By a tube heated by an oil flame.
3. By spontaneous ignition of the oil vapour, due to its compression, and to the heat of the vaporising chamber.

Most of the engines described in this chapter were exhibited at Cambridge in 1894, and details of the experiments made on them will be found in the table of trials. A few are of too recent construction to have been tested.

The **Hornsby-Akroyd** oil engine (1892) was one of the first to introduce a peculiarity distinguishing it from the motors hitherto described. It has neither hot tube nor electric spark, but the charge is fired according to the method described in the third division above. The oil is injected into a hot chamber at the back of the cylinder, into which heated air, compressed by the back stroke of the piston, is forced as it reaches the inner dead point, and the mixture ignites spontaneously. The internal surface of this chamber is provided with radiating ribs, to afford a greater heating area. It is maintained at a red heat by the combustion and explosion of the oil and air at every other stroke. This method has also been introduced into several other engines, English and foreign. The motor is of the usual four-cycle type, and the functions of admission, compression, explosion *plus* expansion, and exhaust are carried out during four consecutive strokes. The action and method of vaporising the oil will be best understood from Fig. 122.

In this figure, which is shown on p. 322, B is the compression space into which the piston does not enter, and C the combustion chamber beyond it. The walls of the cylinder are cooled by a water jacket. The highly heated charge is prevented, by the intermediate compression space B, from coming in contact with the cooler cylinder walls. Below is the lamp L of cast iron, with an asbestos wick, used to heat the combustion chamber or vaporiser at starting. The oil for this lamp is drawn from the same tank as that feeding the engine. Air is admitted above it from a fan, F, worked by hand, and as it enters it rapidly brings the oil to a strong flame, which issues through the hole at the top, and in a few minutes heats the vaporiser C. As soon as the latter is red hot, the current of air is stopped, the lamp extinguished, and the engine works automatically, after a few turns of the flywheel by hand. The T-shaped air and exhaust valves, seen at *c* and *d*, are worked by cams and levers through an auxiliary shaft, geared to the crank shaft in the proportion of 2 to 1. These valves communicate with the cylinder through the same opening, in order that the heat of the exhaust products may warm the fresh air admitted through

valve *d*. Between the vaporiser and the admission chamber is a water-jacketed back pressure valve, to prevent the possibility of premature ignition. The temperature of the air is further raised by the heat of the cylinder, and of the back compression stroke. As the piston reaches the inner dead point, it forces the compressed air into the hot vaporiser, where a small quantity of oil is injected into it. The oil is drawn from a tank in the base of the engine, and a few drops are delivered by the little oil pump O at every other stroke, through a nozzle into the hot chamber C. The oil pump, worked by the same lever as the exhaust, sends the oil to the chamber in a liquid condition, and not, as in some other oil engines, in the form of spray. The heat of chamber C and the pressure of the air charge immediately vaporise it; the maximum pressure at the inner dead point causes the ignition, and the piston is driven out. The burning charge passes into the compression space of the cylinder through a small passage, *s*, that as little heat as possible may be dissipated through the walls, and the pressure of the flame increased. The centrifugal governor G acts on the little valve through which the oil is admitted to the vaporiser, and closes the narrow tube when the speed exceeds the normal limits. At the same time it opens a little bye-pass valve, and the oil is sent back to the tank; thus the oil pump works continuously, the governor regulating only the direction in which the oil passes. The valve box has a water jacket, to keep the oil cool till it reaches the vaporiser. The quantity conveyed to the engine to form a charge is regulated by adjusting the stroke of the oil plunger. The larger engines are started by means of a reservoir, into which air is either pumped by hand, or compressed by the engine before starting. The motor is lubricated in the usual way.

Method of Vaporising the Oil.—The peculiar feature of this engine is, that no attempt is made to vaporise the oil or convert it into spray, until it is actually injected into the combustion chamber. Hence the density of the oil is a point of no importance, and heavier petroleum may be used than in most other engines. The specific gravity of the oil varies from 0·79 to 0·88, and even crude oil may sometimes be utilised. The quantity of oil injected at a time is very small, only about ·033 cubic inch per stroke of the oil pump in a 6 H.P. engine. The proportion of air admitted is sufficient for complete combustion, and there is said to be no heavy residuum. The exhaust products are used to warm the incoming air, the heat of combustion to vaporise the oil, and raise the temperature of the next charge to the ignition point. Much of the heat generated is thus utilised. The consumption of the engine is about 1 pint per hour per B.H.P., and the cost of working under ½d. per

B.H.P. per hour. Fig. 123 gives an indicator diagram of an engine indicating 6·74 H.P. The specific gravity of the oil was 0·854, flashing point 220° F., and the engine made 224 revolutions per minute. The consumption of oil was about 0·9 pint per B.H.P. per hour. The engine is made by Messrs. Hornsby & Sons, horizontal, stationary, from 1½ to 40 B.H.P., portable 3½ to 20 B.H.P., and vertical with two cylinders for launches from 5 to 20 B.H.P. It runs at 250 to 170 revolutions per minute, with a piston speed of 400 to 700 feet per minute. A 40 B.H.P. stationary horizontal engine has been made recently, with a cylinder diameter of 18½ inches by 24 inches stroke. The Hornsby is specially adapted for agricultural or other rough work, because no external flame is required. At the Cambridge Show in 1894 two of these engines were exhibited, and were much commended for steadiness in running. The results of the trials will be found at the end of the book.

Fig. 123.—Hornsby-Akroyd Engine—Indicator Diagram.

Trusty (1891).—A different method of vaporising the oil has been adopted in the Trusty engine, brought out by Messrs. Weyman & Hitchcock, and resembling the gas engine of the same name, with the addition of an apparatus for gasifying the oil. Some years ago an engine was invented by Mr. Knight of Farnham, in which the oil was vaporised in a jacket round the combustion chamber. The patent of this engine has now been acquired by the makers of the Trusty, who have applied and improved the principles of the early motor. In the Knight engine, ignition was obtained by making a flame, produced by the action of bellows, play at the right moment upon a coil of platinum wire. In the Trusty, the charge was at first fired by directing an air jet upon an oil flame, but this method has now been abandoned in favour of ordinary tube ignition.

The engine is made single acting, both horizontal and vertical, with one, two, or four cylinders; the action is similar to that described in the Trusty four-cycle gas engine. Fig. 124 gives an end view, with the method of introducing the oil into the vaporiser. The latter, shown at V, consists of a jacket fitting round the combustion chamber at the compression end of the cylinder, and divided internally into sections. The air admission and exhaust valves, S and S_1, are worked by levers, L and L_1, from a side shaft gearing into the main shaft in the proportion of 2 to 1, as in the Trusty gas engine. At O, O_1, are the screws for adjusting the valves; the exhaust outlet is at E. The

method of vaporising the oil is original. It is drawn through the pipe *p* from a tank below the engine, and pumped from the horizontal pump P through the second pipe p_1, into the column or receiver C at the top of the engine. From here it passes into the jacket or vaporiser V through a small glass tube just above the cylinder, shown in Fig. 126, through which it is admitted drop by drop into V, where it is immediately vaporised, and passes through the vapour valve H to the combustion chamber. The igniting tube I is at the back of the cylinder and evaporating chamber, and is maintained at a red heat by a lamp J, with blow flame. It is the heat of the inner wall, separating the vaporiser jacket from the combustion chamber, which vaporises the oil, except at starting, when a lamp must be used to heat it, and a few drops of oil pumped in by hand. The rod Q, actuating the oil pump P, is worked at M by a hit-and-miss device, controlled by the pendulum governor G. If the speed is too great, the projection on the governor cannot reach the notch on the valve rod in time, a lever D is interposed, and the oil pump does not work. The lever also acts upon the valve H, admitting the oil to the cylinder, and the supply is thus doubly checked by the governor.

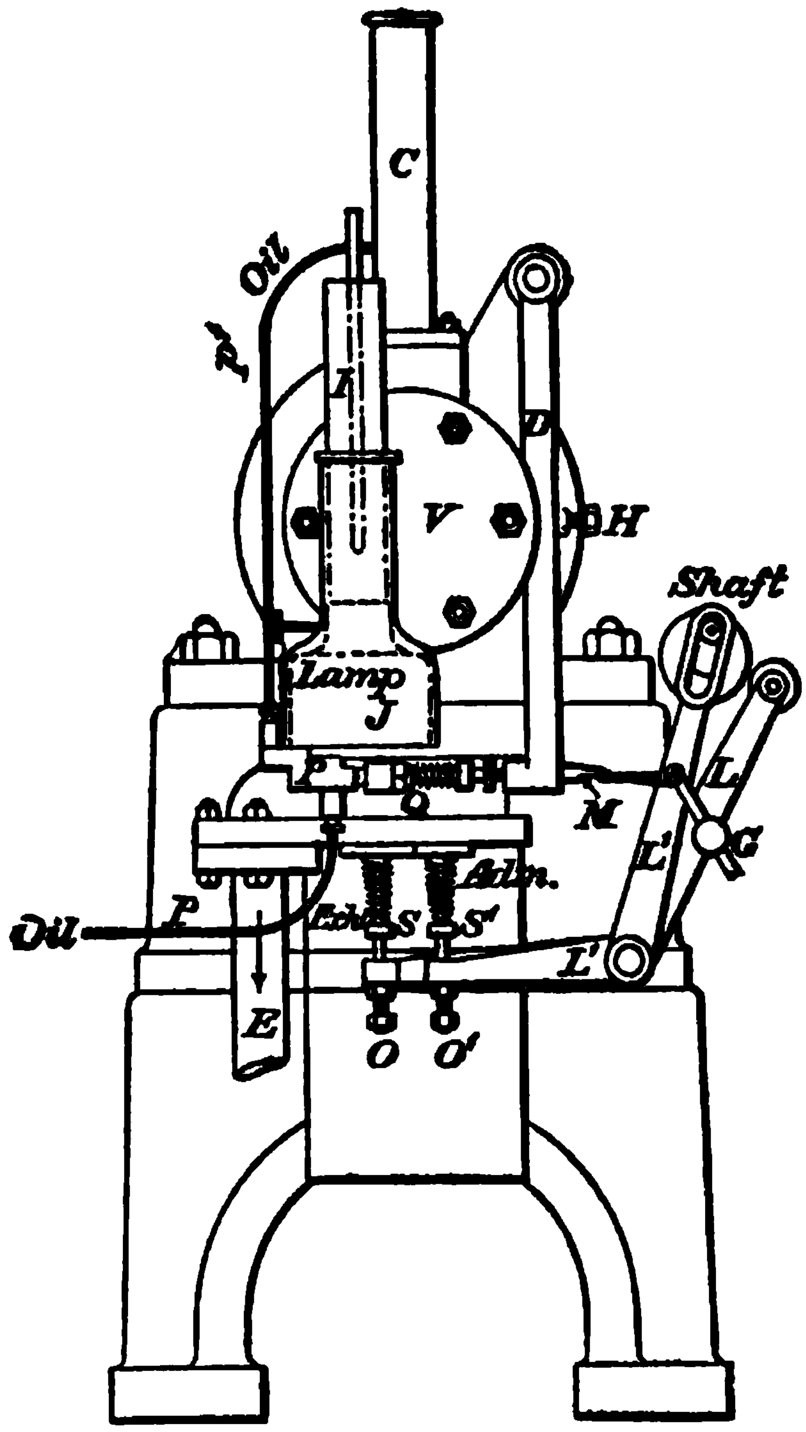


Fig. 124.—Trusty Oil Engine. 1891.

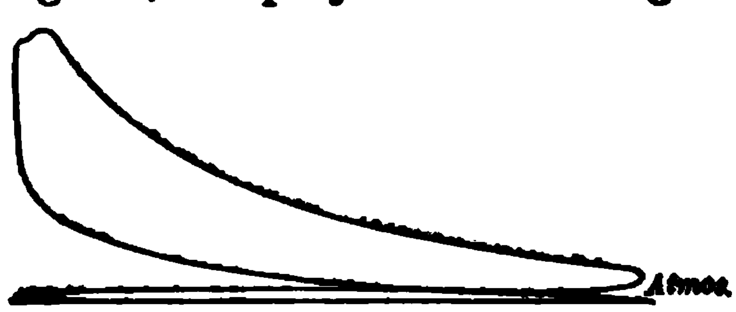


Fig. 125.—Trusty Oil Engine—Indicator Diagram.

As the combustion of the charge takes place in the compression chamber, the jacket round it becomes so hot that the oil, as it enters, is instantly turned into vapour. The out stroke of the

piston draws in a charge of fresh air through the valve S_1, and at the same moment, through valve H, the vaporised oil is admitted into the compression chamber from the jacket. The oil vapour and air mingle in the cylinder, and are compressed by the return stroke of the piston, driven up the tube, ignited in the ordinary way, and explosion and expansion of the charge follow. The oil is vaporised by the heat of explosion, during which the highest temperature of the cycle is reached, and greater pressures are said to be attained than in the Priestman engine, where the oil is vaporised by the heat of the products of combustion only. The Trusty engine also runs at higher speeds than the Priestman, and gives a good heat efficiency. The special feature of the engine is the vaporisation of the oil drop by drop, as it is required, the quantity being regulated by the stroke of the oil pump, which in a 4 H.P. engine is about $\frac{1}{4}$ inch diameter. As the oil is not sprayed before it enters the cylinder, neither its density nor the varying temperature at which it evaporates affect the working of the engine. There is sometimes

Fig. 126.—Trusty Oil Engine—External View. 1891.

a little residuum, because the petroleum is turned into true oil gas by the heat of combustion. The parts and passages being easily accessible, the occasional cleaning required is carried out without difficulty. Broxbourne lighthouse oil, distilled from Scotch shale, with flashing point 150° F. and specific gravity 0·81, is usually employed, but a much heavier oil with flashing point 250° F. may be used.

Trials.—In a two hours' trial on a Trusty oil engine made by Mr. Beaumont, the specific gravity of the oil was 0·810. The engine indicated 6·2 H.P., and gave 4·28 H.P. on the brake the mechanical efficiency was 69 per cent., and the speed 230

revolutions per minute. The oil used was 0·963 lb. per B.H.P., and 0·667 lb. per I.H.P. per hour. All the items of heat expenditure were carefully noted; particulars will be found in the table of Trials. The ratio of heat shown in the indicator diagram as work done, to that supplied in the oil was about 20½ per cent. Another trial made by Mr. Beaumont on an engine of similar dimensions, giving 5·98 B.H.P., and 7·04 I.H.P., showed a consumption of 0·82 lb. oil per B.H.P., and 0·69 lb. per I.H.P. hour. In the 4·63 B.H.P. engine shown at the Cambridge trials, the consumption was 1·15 lb. per B.H.P. hour. Fig. 125 gives an indicator diagram taken during the first trial, and Fig. 126 an external view of the engine. The makers' types range from 1½ to 10 B.H.P., single cylinder, 10 to 21 B.H.P. for two cylinders side by side, horizontal; portable engines are made from 4½ to 9 B.H.P. A new vertical type has lately been brought out for electric lighting, launches and other work, single cylinder 1¼ B.H.P., with two or three cylinders from 10 to 31 B.H.P. It has also been adapted for propelling road carriages. The speed of the engine per minute is from 300 to 220 revolutions.

Roots.—The original type of this engine was described in *The Engineer*, September 30, 1892, but the design has since been improved and simplified. As at present built, the motor is of the usual four-cycle kind, with several novelties, chiefly in the method of vaporising the oil, and mixing it with hot air. Instead of running by gravity from a receiver above, the petroleum is now fed to a reservoir, and thence to the cylinder by a pump. The vaporiser consists of a cylindrical chamber placed over a lamp, and containing a series of spiral spaces, through which the air for vaporising the oil is drawn by the suction of the piston, and heated in its passage to the oil valve. The small horizontal oil pump is worked by a cam and lever from the side shaft. It carries a reciprocating spindle with one or more grooves, which are filled with oil each time the stroke of the pump works the spindle into the oil chamber. During the return stroke it is brought in contact with the current of heated air from the vaporiser jacket, which sweeps off the oil from the grooves, and carries it on as spray to the chamber. Here it is completely vaporised by the heat and the force of the air blast, and mixed with a further supply of heated air as it passes to the admission valve. At first all the air for the charge is drawn through the vaporiser, and heated. As soon as the parts are hot and fairly at work, another supply of air, previously warmed by its passage through the exhaust chamber, is admitted, to ensure the complete mixing and combustion of the charge. The speed of the engine is ingeniously regulated by a ball governor acting on the spindle of the oil pump. The latter carries several steps, and, by shifting them, the governor determines the number of

grooves entering the oil chamber to be filled at each stroke, and hence the quantity of oil presented to the air current, and evaporated. If the normal speed is greatly exceeded, the exhaust valve is also held open. Minute variations in the quantity of oil and strength of the charge are thus obtained. With small engines there is only one groove, and the governor stops the pump altogether, if the speed is too great.

The oil tank is in the bed plate. The side shaft works a cam with steps for the exhaust and two small pumps, one to feed the oil reservoir, the other for supplying air under pressure, to raise the oil for the lamp. An ingenious method has been adopted to regulate the opening of the exhaust at starting. It is at first kept in position by a finger piece on a collar on the side shaft. As the engine begins to work, the finger follows a screw thread cut in the collar, which after two revolutions brings it to rest, and the exhaust lever acts as usual. Thus the degree of compression at starting, and the quantity of air drawn in, are gradually and automatically increased.

A 7 B.H.P. Roots engine was exhibited at the Cambridge show, in which the oil consumption was 1·49 lb. per B.H.P. hour. The author had lately (1896) the opportunity of testing a 7 B.H.P. engine, and found the consumption of oil 1·1 lb. per B.H.P. hour. The motor is made both horizontal and vertical, in sizes from ½ to 15 B.H.P., and runs at 370 to 200 revolutions per minute. The vertical type has been adopted for river use, boats and launches, by Messrs. Vosper of Portsmouth (see chapter on Practical Applications).

Lamp.—As many oil engines have a pressure lamp for heating the vaporiser, it will be useful to give a general description of that used in the Roots and other motors. The reservoir for containing the oil is fitted with a pressure gauge, and is sufficiently strong for a pressure of 25 lbs. per square inch. It has a funnel with air-tight joint, and an air pump with plunger piston and delivery valve. The end of the supply pipe to the burner is about 1 inch from the bottom of the reservoir. The burner or lamp, which has no wick, consists of a bent tube filled with oil, in a cylindrical casing, a clear passage being left through the centre of the casing for the flame. The length of the coil presents a sufficient heating surface to the flame to vaporise the oil. The latter, sent on from the reservoir by the air pressure, is thus completely evaporated before it escapes from the bottom of the coil, and is ignited. The lamp provides the heat for its own vaporisation, an arrangement which will be found in other motors, as the Howard, Griffin, &c.

To start the engine, the burner is first heated by a piece of asbestos dipped in oil, and the air pump worked by hand till the requisite air pressure is attained. The pressure of air forces the oil through the pipe to the burner, a current of air

is carried with it, and thus the oil, when it issues out at the bottom of the coil, is not only vaporised but mixed with air, and burns with a strong blue flame and considerable noise.

Crossley-Otto.—The Otto may truly be called the prototype of all modern gas engines, and to its many advantages has been added that of working with petroleum. The oil motor introduced by Messrs. Crossley does not differ much from the Deutz-Otto, described among the German petroleum engines. It has a timing valve and tube ignition, and like all other oil motors the cylinder is water jacketed. In the 7·3 B.H.P. engine exhibited at the Cambridge trials the oil was sent to the vaporiser by a pump, the air entering through an automatic valve. The exhaust and the valve admitting the charge to the cylinder were worked from the side shaft, the governor acting upon the former. As in many other oil engines, the lamp is an important feature. It is fed with oil under pressure from a small air pump, charged by hand once or twice a day, and heats not only the tube, but a coil above it forming the vaporiser. The air to vaporise the oil is previously heated by the exhaust products. The consumption of this engine at Cambridge was the lowest recorded, 0·82 lb. per B.H.P. hour, and it was much commended. It is made horizontal in sizes from 3½ to 15½ B.H.P., and runs at 200 to 180 revolutions per minute.

Griffin (1892).—This oil engine, brought out by Messrs. Griffin, of Bath, must be distinguished from the Griffin gas engine, made by Dick, Kerr & Co., of Kilmarnock. The ordinary Beau de Rochas cycle is used, and there is an explosion every other revolution. It is a single cylinder, horizontal engine, and the admission and exhaust valves are driven from a side shaft, geared to the crank shaft in the usual way. The novelties claimed for this engine are the method of vaporising the oil, of ignition, and of governing. It is the only engine, with the exception of the Priestman, in which the oil is sprayed for the charge. The vaporiser is placed in the engine bed, below and at right angles to the cylinder. No nozzle is used, as formerly, to inject the oil. The spray is formed by a blast of air compressed in a pump to 12 lbs. per square inch, which opens the oil valve, sucks up the oil as it issues, draws it by induction up a diagonal tube, and carries it as fine spray into the vaporiser. Here the oil is converted into vapour by the heat of the chamber, which is ribbed internally to afford greater heating surface, and surrounded by a passage for the circulation of the exhaust gases before discharging to the atmosphere. Much of the heat of explosion must thus pass into this chamber. As the oil vapour emerges from the vaporiser at the other side of the engine, it is carried to the cylinder above, and mixed in its passage with more air, to form an inflammable charge. This air is also heated

by the exhaust gases, and by passing through a division in the base of the engine. The charge then enters the cylinder, and is ignited by a tube, maintained at a red heat by an oil spray Bunsen flame in the following way:—A small quantity of oil trickles from the tank to a little vessel, where it is drawn upward by capillary attraction. It is next broken up into spray by a blast of air from the pump, and carried forward into a pipe kept at a high temperature by the heat from the burner. Here it is vaporised, ignited at the Bunsen burner, and the flame plays continually on the tube.

Governing of Griffin and other Oil Engines.—To regulate the speed of an oil engine by reducing the number of explosions, cutting off the supply of oil, and passing air only through the cylinder, is not altogether desirable. If there is no explosion, no heat can be communicated from the exhaust gases to the vaporiser. The latter becomes chilled, and the next time oil is admitted, the temperature is not high enough to evaporate it completely; unburnt oil passes into the cylinder, and waste and deposit of residuum are the result. In the Griffin engine the centrifugal governor acts upon the air pump, and throws it out of gear, if the normal speed is exceeded. Not only does no oil spray reach the vaporiser, but there is no pressure of air to lift the oil valve. To prevent any escape of heat, the governor also closes the two valves placed side by side, for admitting the charge to the cylinder, and discharging the exhaust gases after they have heated the vaporiser and fresh mixture. No charge either enters or leaves the cylinder, and therefore the latter does not become chilled by an inrush of cold air. At starting the air pump is worked by hand, and the oil spray thus formed is ignited, and enters the vaporiser as a powerful flame. In ten minutes it is said to be sufficiently hot to work the engine. The air pump is then connected to an eccentric on the side shaft. An 8 B.H.P. stationary Griffin motor was exhibited at Cambridge by Messrs. Samuelson, of Banbury. It is made horizontal, in sizes from 2 to 20 B.H.P., and runs at 240 to 200 revolutions per minute. The French patentees are MM. Crozet et Cie., Chambon, Loire. Drawings of the engine will be found in *Engineering*, November 4, 1892. No trials upon it, except at Cambridge, appear to have been made.

Weatherhogg.—The Safety engine, made on Weatherhogg's Patent by Messrs. Penney & Co., of Lincoln, is specially intended for use in the Colonies, or as a portable motor for industrial purposes. The crank, crank shaft, and connecting-rod are all enclosed. The oil is drawn from a tank in the bed plate, and pumped into the vaporiser at the back of the cylinder. The latter is heated by the same flame as the ignition tube, and vaporisation is said to be complete. The valves are worked from a side shaft which also drives the governor, and the engine does

not apparently differ from the usual four-cycle type. The oil used is of 0·80 specific gravity and upwards, and great care is taken to prevent it from coming in contact with the atmosphere. The engine is made single cylinder, horizontal, from 1 to 10 H.P., with a speed of 300 to 175 revolutions, for larger sizes with two cylinders. It can also be adapted to work with lighting gas if required.

Rocket (1893).—A petroleum engine of this name has been introduced by Messrs. Robert Stephenson & Co., of Newcastle. It is made under Kaselowski's Patent, and is similar in design to the engine constructed by the Berliner Maschinenbau Gesellschaft, (formerly Schwartzkopff). In this motor, petroleum from a tank above the cylinder flows into a receiver, in which the level is kept constant by a float. From thence it passes to the vaporiser, a cylindrical chamber heated at starting by a lamp, and afterwards by the exhaust gases. On its entrance the oil is sprayed by an air current, diluted with a further quantity of air, and vaporised by the heat as it passes downwards. Before it reaches the clearance space, it is mixed through an automatic valve with sufficient air to make it inflammable, and the charge is admitted to the cylinder through a valve opened by the governor. If the normal speed is exceeded, a trip piece on the governor does not catch in the spindle of this valve, and no charge enters. At the same time another valve is opened, and air is allowed to escape, thus reducing the pressure in the cylinder. Ignition is by tube with a timing valve, worked by a cam and lever from the side shaft. Drawings and a description of this engine will be found in *The Engineer*, May 5, 1893. It is made horizontal, single cylinder, in sizes from 1 to 10 H.P., and neither it nor the Weatherhogg appear to have been yet tested.

Fielding (1894).—The oil engine brought out by Messrs. Fielding & Platt, of Gloucester, is similar to their gas motor, with the addition of a vaporiser. The method of vaporising the oil is ingenious, though not perhaps absolutely novel. The combined vaporiser and igniter consist of two horizontal tubes, one above the other, contained in a chamber forming a prolongation of the cylinder. Both are heated by a blast oil lamp, the lower tube, in which the charge is ignited, being brought to a cherry-red, and the upper to a dull-red, heat. A jet of oil is sent by a little pump into the upper tube, together with a small current of air previously heated by the lamp. The two pass through a valve into the lower igniting tube, the heat of which ensures complete vaporisation, and thence to the cylinder, where they are mixed with more air, entering through an automatic valve, to render the charge explosive. The next compression stroke drives them back into the lower ignition tube, which is open to the cylinder without a timing valve; the charge is fired

and the cycle completed. The lamp is fed from a small separate reservoir, the pressure in which is maintained, and the oil raised for the lamp, by means of a hand pump at starting. As soon as the engine is at work, the piston during the exhaust stroke uncovers a small port opening to the oil receiver, and the pressure of the exhaust gases is utilised to force a small portion of the oil into the tube leading to the lamp, which is thus fed automatically. The admission and exhaust valves and pump are all driven by one cam from the side shaft, and acted on by the ball governor. If the normal speed is exceeded, the exhaust is held open, the supply of oil cut off, and the automatic air admission valve is closed by the fall in pressure. The makers consider that ignition is more certain if the vaporiser is heated by a lamp, than if the internal heat of the engine alone be relied on to raise the temperature, but for small powers the lamp can be dispensed with. The engine is made in sizes from 2½ to 16 B.H.P., horizontal, both portable and stationary, and runs at 240 to 180 revolutions per minute. An 8 B.H.P. motor was exhibited at the Cambridge Oil Engine Trials.

Robey (1894).—The Robey oil engine was also shown at Cambridge in 1894, and at Darlington in 1895. It is similar to the four-cycle gas engine of the same makers, with the addition of a vaporiser, and embodies some of the latest improvements in oil engines, which all tend in the direction of greater simplicity. It has no injection tube or external lamp, nor is the oil sprayed or broken up before it enters the vaporiser. Heavy petroleum is used with a flashing point of 240° F. It is drawn from a tank in the base by a small oil pump worked by an eccentric on the valve shaft, pumped into an accumulator, and thence to a trip box. The governor on the valve shaft actuates the lever and spindle of the trip box, and sends on a small quantity of oil direct to the vaporiser. In order that there may always be a sufficient supply of oil to the cylinder, the pump delivers more to the accumulator per stroke than is drawn from the trip box, the excess being sent back to the reservoir; thus a steady pressure is maintained by the accumulator in the oil valve or trip box. The combined vaporiser and igniter are placed in the centre of the combustion chamber, at the back of the cylinder. Behind them is the exhaust valve, the air admission is immediately below the vaporiser, and both valves are worked by cams and levers from the side shaft. The products of combustion pass through the vaporiser before they are discharged, and combine with the heat of the explosions to keep it at a high temperature. When the oil is delivered to the vaporiser the air valve is lifted, a supply of air heated by passing through the base of the engine enters, and mixes with the vaporised oil to form the charge. The next compression stroke drives them back into the vaporiser, which communicates

with the cylinder through a narrow opening without a timing valve. The charge is fired, and explosion takes place not only within the vaporiser, but outside in the combustion chamber. The return stroke drives out the products of combustion through the chamber, thus sweeping it clean, and keeping it free from tarry deposit. The exhaust valve and explosion chamber are water jacketed, as well as the cylinder, but have a separate drain pipe. The vaporiser is heated at starting by a lamp fed by a blast of air from a fan worked by hand, but in the latest types the fan has been dispensed with, and a new kind of lamp is used, which is almost automatic in its action. The ball governor acts through a hit-and-miss arrangement on the oil supply valve, and throws it out of gear if the normal speed is exceeded, thus wholly suspending the admission of oil. The engine is made horizontal, single cylinder, stationary in sizes from 3½ to 20 B.H.P., and portable from 7 to 14 B.H.P., and runs at 300 to 200 revolutions per minute. For larger sizes two cylinders are used.

Premier (1894).—In this engine made by Messrs. Wells, of Sandiacre, all the valves, as well as the governor and oil pump, are driven by one cam from the side shaft, which actuates a vertical rocking lever, held in position by a strong spring. The lever opens the exhaust and admission valves, while a link from it works the oil pump. The top of the lever terminates in a knife edge, and the governor consists of a simple horizontal bar above it, balanced on a pivot in the centre, with a notch at one end, and weighted at the other, furthest from the lever. At ordinary speeds the spring keeps the lever in position, the exhaust is closed and the admission valve opened at the right moment, and the knife edge is clear of the notch. If the number of revolutions is increased, the horizontal bar does not rise in time, the notch is caught, the movement of the lever arrested, and consequently all the valves thrown out of gear. The exhaust remains open, and no charge enters the cylinder, or is sent to the oil valve. The vaporiser is a separate chamber at the back of the cylinder, heated, as well as the ignition tube, by a lamp; the latter is fed by a blast of air from a pump, worked by an eccentric from the side shaft. The oil runs from a receiver above into the oil valve box. Here a fixed quantity is measured into a small cavity in the plug of the rotatory oil pump, which is driven by the link off the rocking lever. As the plug turns, the oil is discharged on to a hot slanting iron plate, and is vaporised as it runs down. The opening of the admission valve induces a current of air through the vaporiser, which sucks the oil vapour into the cylinder. Thus it is converted into vapour before it is mixed with any air, and in accordance with the latest views it is not sprayed or broken up, but dropped in a liquid condition into the vaporiser. Air is only added to it once to render it

inflammable. Heavy oil, Russian or American, can be used, and as the oil is vaporised in minute quantities as required, its density is a point of no importance.

This oil engine is made single cylinder, horizontal, in sizes from 2 to 15 B.H.P., and runs at 260 to 200 revolutions per minute. A 6½ B.H.P. motor was exhibited at Cambridge, and was commended for the simplicity of the working parts.

Tangye (1895).—It would be difficult to design a simpler oil engine than the Tangye, introduced in 1895. There is no pump, fan, or storage of oil or air under pressure, and only two valves, for admission and exhaust, worked by cams from the side shaft. A peculiar feature is that the oil is not perfectly vaporised when it enters the cylinder, but only becomes so when driven back during the compression stroke into the hot vaporiser and combustion chamber. Any ordinary oil can be used. From a small tank above, containing sufficient for a day's supply, the oil runs to the admission valve, the quantity per stroke being adjusted automatically. From hence it passes, together with a current of air at high pressure, to the vaporiser, placed between the cylinder and the hot-ignition tube. At starting the vaporiser is heated by a small wickless oil lamp, but as soon as the engine is at work the lamp is shifted beneath the ignition tube, and the proximity to the cylinder and tube are sufficient to keep the vaporiser at a high temperature. The oil already partly mixed and vaporised is carried forward with the air into the cylinder, the next stroke sends the charge back through the vaporiser, where it is finally converted into vapour, to the ignition tube, communication with which is opened by a timing valve worked from the side shaft, and the cycle is then completed. The governor acts by holding the exhaust open and the admission valve closed, thus checking the supply of both oil and air to the cylinder. The engine is made horizontal, single cylinder, in sizes from 1 to 6 B.H.P., and runs at 230 to 200 revolutions per minute. The consumption in a 4 B.H.P. motor is said to be less than 1 lb. per B.H.P. hour. Fig. 127 gives a general view of this engine.

Howard (1895).—An oil engine has lately been brought out by Messrs. Howard Brothers, of Bedford. The Otto cycle is used, and the motor does not differ in construction from others, except in the method of vaporising. The oil is drawn from a tank, and delivered through a nozzle by a small oil pump, worked by a cam and lever from the side shaft, into the vaporiser. A small current of air is drawn in at the same time, sufficient to break up and spray the oil, but not to render it inflammable. The vaporiser at the end of the water-jacketed combustion chamber is in three divisions, the centre being the hottest, and is heated by a lamp, which also serves to maintain the ignition tube at a red heat. The oil for this lamp is fed from a

separate receiver, into which it is forced by the pump, the latter thus supplying oil both to the vaporiser and to the lamp. The surplus is returned to the tank. The already vaporised oil passes to the admission valve, and thence to the combustion or mixing chamber, where it is diluted with the main supply of

Fig. 127.—Tangye Oil Engine. 1895.

air, drawn in through an automatic valve from the base of the engine, and the two are conveyed to the cylinder, compressed and ignited in the usual way. Communication between the vaporiser and combustion chamber is shut off by the admission, or as it is sometimes called the vapour valve, except during the injection of oil. There is no timing valve to the tube except in large

power engines, the moment of ignition being determined by the length of the tube. The two valves regulating the supply of oil to the vaporiser, and the admission of the charge to the cylinder, are both controlled by the ball governor, on the hit-and-miss principle. As in the Griffin engine, the heat of the lamp vaporises the oil supplying it. The Howard engine is made stationary in sizes from 2½ to 12 B.H.P., and portable from 4 to 12 B.H.P. It can be adapted for lighting gas, but hitherto only engines to work with heavy petroleum have been constructed. In the portable engine the circulating water is cooled by a current of air.

Clarke, Chapman & Co. (1894).—The oil engine made by this firm is similar in design to their gas engine, with the addition of a vaporiser. It has a circular rotary valve, driven from a valve shaft, and revolving at one quarter the speed of the engine. The method of vaporising the oil is shown in the accompanying sketch (Fig. 128). The vaporiser is a chamber having two concentric spaces, one within the other, the exhaust gases from the engine being carried into the hollow central space, and thence discharged. The heat thus obtained is sufficient to vaporise the oil, which flows by gravity from a tank to the cone over the exhaust. At the same time, heated air is drawn in by the action of the engine, and breaks up the oil, already volatilised by the heat of the exhaust gases. Both pass as shown in the drawing to the inspirator, and are mixed on their way with another supply of air, drawn in automatically through a nozzle by the suction of the piston. Thus air is twice mixed with the oil vapour, and the inflammable charge is then treated in the same way as in the Clarke-Chapman gas engine. It is conveyed by the supply pipe to the rotary valve and thence to the engine, and the speed regulated by a throttle valve in the supply pipe, acted on by the governor, as already described. If the normal speed is exceeded, the governor checks, not the richness of the charge, but the quantity passing to the engine, and thus the degree of compression and strength of the explosion. Ignition is effected either by an electric spark or a tube; in the latter case, the tube is kept hot by a gas flame or an oil burner. To start the engine the makers prefer to use a small quantity of light benzoline, which with electric ignition will, it is said, bring it into working order in 2½ minutes; it can then be driven with ordinary oil. Rather longer time is required if tube ignition be used, and the engine started with heavy petroleum, in which case the vaporiser must be previously heated. To cleanse the cylinder as far as possible of the products of former combustion, higher compression than usual is employed. In a test made at the Works at Gateshead on an engine developing 11½ B.H.P. the charge was compressed to 45 lbs., and the maximum pressure of explosion was 165 lbs. per sq. inch.

Fig. 128.—Oil Engine—Clarke, Chapman & Co. 1894.

The engine is made in sizes from 1 to 45 B.H.P., horizontal, single cylinder, or for boats with two cylinders, and runs at 180 to 240 revolutions per minute. A 6 B.H.P. stationary and a 12 B.H.P. portable engine were exhibited at Cambridge, and were the only motors using electric ignition. The consumption in the portable engine was 1·25 lb. oil per B.H.P. hour. A 14 B.H.P. portable engine was exhibited at the Darlington Agricultural Show in 1895.

Clayton and Shuttleworth.—It is claimed for the engine made by this firm that it will work with any oil, however heavy, and even with Broxbourne shale oil of 240° F., flashing point. The motor is of the ordinary four-cycle, single acting type, with lift valves worked from a side shaft in the usual way. The oil is drawn from a tank above, and sent to the vaporiser drop by drop as required by a small oil pump, acted on by a pendulum governor. The speed can be varied within certain limits, while the engine is running, by adjusting the weight on the pendulum rod. If the normal number of revolutions is exceeded, the governor cuts off the supply of oil. The vaporiser is simply an extension in the shape of a jacket at the back of the cylinder, and is said to vaporise the oil thoroughly, without deposit, and without requiring an air blast to break it up. The ignition tube is kept at a red heat by a small blow lamp, which, with the heat of the explosions in the cylinder, suffices to maintain the vaporiser at the required temperature. From hence the oil vapour is drawn into the cylinder by the suction of the piston, together with a supply of air through a separate valve. To start the engine, the vaporiser must be previously heated, and oil pumped into it by hand. The Clayton is one of the latest and simplest oil engines. Trials were made on a 6 B.H.P. motor in 1893, and showed a consumption per B.H.P. hour of 0·82 lb. of oil of 0·80 density, and 19,500 T.U. heating value. The mechanical efficiency was 85 per cent., and heat efficiency 16 per cent., a good result for so small an engine. The low consumption showed that the oil was more or less completely vaporised. The engine is made horizontal, single cylinder, in sizes from 1½ to 12 B.H.P., and runs at 260 to 240 revolutions per minute.

Campbell.—This is a four-cycle oil engine of the Otto type, resembling the gas engine by the same makers, with the addition of a vaporiser. Like most of the latest English petroleum motors, it is very simple in construction, having no fan or pump; there are only two valves, inlet and exhaust. The oil flows by gravity from a tank above to a small supply pipe terminating in two fine holes round the automatic admission valve. The suction of the piston during the out stroke draws down this valve, a current of air enters from above, and a minute quantity of oil through the holes at right angles to it. The oil is broken

up by the inrush of air, and sprayed by being projected against the sides of the valve chamber. The two then pass to the vaporiser below, which with the ignition tube is contained in a chamber at the side of the cylinder, and kept at a red heat by the flame of a lamp. The exhaust is at the back of the engine The oil already sprayed is vaporised by the heat of the chamber, and the charge passes to the cylinder; the next compression stroke drives it into the ignition tube, where it is fired in the usual way. There are no timing or vapour admission valves. In so simple an engine the speed is easily regulated. The ball governor on the side shaft acts on the exhaust, and holds it open if the normal speed is exceeded. As there is no vacuum in the cylinder, the automatic admission valve does not rise, and no air or oil can enter. A 4 B.H.P. engine was exhibited at the Cambridge trials, and consumed 1·15 lb. oil per B.H.P. hour. It is made horizontal, single cylinder, in sizes from $1\frac{1}{4}$ to 30 B.H.P. for fixed, and $3\frac{1}{2}$ to 17 B.H.P. for portable engines, and vertical from $1\frac{1}{4}$ to $3\frac{1}{2}$ B.H.P., and runs at 240 to 160 revolutions per minute. A vertical two-cylinder type is also made for boats.

Britannia (1895).—A new motor of their own design, (Gibbon's patent), has lately been brought out by the Britannia Co., and was exhibited at Darlington in 1895. The vaporiser, which also serves for the ignition of the charge, is an extension at the side of the cylinder, and the oil is injected into it by a small pump worked by a cam on the side shaft. It is heated by a lamp at starting, the heat of the explosions is said to be afterwards sufficient to vaporise the oil, and fire the charge. Air is drawn in from a jacket surrounding the vaporiser and combustion chamber, and is admitted through ports in a piston valve, which also carries another set of ports to discharge the exhaust products, and is worked by a cam on the valve shaft. From hence the charge passes to the cylinder, with which the vaporiser communicates. The governor acts on the oil pump, and increases or diminishes the time during which it delivers oil to the vaporiser, in accordance with the speed. No trials on this engine have yet been published. A drawing is given in *Engineering*, Feb. 21, 1896.

The **Reliance** is an oil motor of the ordinary type, made by Messrs. Carter, of Billingshurst, in sizes from 2 to 8 B.H.P., and runs at 240 to 200 revolutions per minute. The vaporiser consists of a jacket surrounding the ignition tube, into which oil is sent by a pump, together with a small quantity of air, and thence to the mixing chamber. The hot air carries the oil with it, and the heat ensures its vaporisation. As the charge reaches the admission valve, it is diluted with a further supply of air through an automatic valve. The oil for the lamp is drawn from the oil tank, and forced through a fine jet under pressure

from an air receiver. The governor acts upon the oil pump, and if the normal speed is exceeded, it returns the oil to the tank.

The **National** Gas Engine Company, Ashton-under-Lyne, also make oil engines on the Otto cycle, in sizes from ½ to 8 B.H.P.

CHAPTER XXIV.

AMERICAN GAS AND OIL ENGINES.

CONTENTS.—Caldwell—Foos—Kane—Kane-Pennington—Nash—Safety—Van Duzen—Hicks—Hartig—Pacific—Union—Sintz—Webster—White and Middleton—Raymond—Backus.

THE small number of gas and oil engines produced in America may be partly attributed to the low price of coal in that country, which renders it unnecessary to seek any cheaper motive power than steam. Although oil in large quantities is obtained in Pennsylvania and other places, it is chiefly used under boilers to generate steam, as at the Chicago Exhibition, where fifty-three boilers were fired with it. The following engines represent the chief types made in the United States. Most of them are intended to be driven either with gas or benzine (light petroleum). Ordinary heavy petroleum is not much used in America to generate power in an engine, the lighter oils being preferred, as easier to handle.

Caldwell.—The Caldwell-Charter engine, made by Messrs. Caldwell & Son, Chicago, forms an exception to the general rule, and may be worked with either gas or ordinary petroleum. In the latter case the oil is drawn from a reservoir in the base, and forced by a small pump, close to and worked from the crank shaft, into a brass pan, where it is mixed with air in the proper proportions. The air is drawn in through two pipes from the base of the engine, and the admission regulated by the governor on the crank shaft. The oil pump, air admission valve, and exhaust are driven by rods from a wheel geared 2 to 1 to the crank shaft. The engine works with the ordinary four-cycle, has a water jacket, and ignition is by a tube heated by a small gazolene burner. A 95 I.H.P. engine is running at Camden, U.S.

Foos.—Another American engine, working with either gas or light petroleum spirit (benzine), is made by the Foos Gas Engine Company, Springfield, Ohio. The motor is fired electrically, the connection and separation of the electrodes being effected from the main shaft through gear wheels. No attempt is made to vaporise the oil. It is contained in a tank at the

side of the engine, and air, previously warmed by passing round the exhaust valve, is drawn by the suction stroke of the piston through the petroleum vapour, which it absorbs in its passage to the admission chamber. The engine is of the usual four-cycle type.

Kane.—Of the same class of motor is the Kane, built by Messrs. Kane, of Chicago. The carburator is simply a small circular tank, divided into annular concentric spaces, partly filled with light petroleum spirit, through which air is drawn, and is charged with oil vapour in its passage. No heat is applied to the air or oil. The exhaust is driven from an eccentric on the crank shaft, the admission valve by a lever acted on by the governor. The engine is fitted with reversing gear, and has been especially adapted for marine use.

The **Kane-Pennington** engine, which has recently made much stir both in England and the United States, is worked with petroleum on the Otto cycle, but having been applied only to propelling bicycles, a detailed description of it scarcely falls within the scope of this work. It appears unquestionably to be lighter and smaller for a given power than any oil engine that has yet been brought out. A speed of 2,000 revolutions is said to be attainable. The charge is fired by electricity, and an electric spark is twice passed through it, first at the dead point, to mingle the gas and air, and a second when the piston is 45° out, to ignite the mixture. It is to the first or "mingling spark" that the extraordinary results obtained are attributed.

Nash.—A vertical two-cycle engine working chiefly with gas, and not fitted with any carburating or vaporising apparatus, is the Nash, made by the National Meter Co., New York. As in some other engines already described, the crank is enclosed to form a chamber for compressed air, and the motor resembles the Day* in some respects, though not so simple, and has an explosion every revolution. The charge is compressed below the piston, and passed up through a passage in the side of the cylinder to the top, where combustion takes place. Ignition is by a flame in a circular chamber, which communicates with the cylinder through a diagonal passage, and a slide valve worked by a cam from the crank shaft. The admission valve is driven in the same way, and the exhaust ports are uncovered by the piston at the end of the out stroke.

Safety.—The Safety Vapor Engine, made by the Company of that name in New York, is a small vertical gas engine of the usual four-cycle type, which can also be driven with benzine. It has one noticeable feature. The valve for admitting the charge to the cylinder and expelling the burnt products is a circular rotary valve, worked by a chain revolving on a pulley

* Described in the first edition of this book, p. 135.

of twice the diameter of a smaller pulley on the crank shaft, from which it is driven. Although hitherto made only in sizes from ½ to 6 H.P., the engine is intended for marine use, and has frictional driving gear for connection to the propeller shaft.

Van Duzen.—A more important motor, made in several types, stationary and portable, for both gas and petroleum, is built by the Van Duzen Gas and Gazolene Engine Co., of Cincinnati. The engine is horizontal, of the four-cycle type; the admission, ignition, and exhaust valves are worked by rods and cams on an auxiliary shaft below the crank shaft, and revolving at half the speed. This engine is fitted with a carburator, though no heat is used to vaporise the oil. Light petroleum spirit is contained in a chamber at the side of the engine. Air is drawn upwards into a vertical tube below this chamber, and lifts a valve, causing the oil to flow down and mingle with it, as it forces its way through another lift valve, and down the sides of the vertical carburator. The petroleum is vaporised by the force of the air current, as it drops through gauze rings. At the end of the admission stroke the flow of air ceases, the valves fall back on their seats, and the supply of oil is cut off. Hot tube ignition is used, and above the chimney protecting the tube is a ball, which is said to act as a cushion, and disperse the waste products in the ignition tube. This engine is especially adapted for portable motors.

Hicks.—The only noticeable feature of the twin-cylinder Hicks gas engine, made at the works of that name, Cleveland, U.S., is that the two cylinders are placed vertically one above the other, and are supported on the same frame. In other respects the engine follows the usual four-cycle series of operations, but having two cylinders, an explosion in one or the other is obtained at every revolution.

Hartig.—A small vertical engine, in sizes from ½ to 8 H.P., is made by the Hartig Gas Engine Co., Brooklyn, New York. It is worked with gas only, and does not appear to have been adapted for petroleum. The usual four-cycle is employed. There are four valves—the governor, admission, ignition, and exhaust. The admission of the gas and air is automatic; the other valves are driven by rods, cams, and gear wheels from the crank shaft.

Pacific.—An engine using the ordinary four-cycle, with electric ignition, and in which the motive power is derived from either gas or gazolene, is the Pacific, made by the Union Gas Engine Co., of San Francisco, and the Globe Gas Engine Co., of Philadelphia. It is especially adapted for marine use, fitted with reversing gear, and has a clutch lever for starting and stopping the propeller shaft. Water for the cooling jacket is drawn from and returned to the water round the boat. The engine itself is never reversed, but only the direction of motion of the propeller and secondary engine shafts. The exhaust valve is raised once

in every two revolutions by a double-grooved cam on the crank shaft, into which a projection fits, after the same manner as in the Daimler engine. The governor acts on the exhaust valve, and holds it open if the normal speed be exceeded. The vaporisation of the oil is effected as in the Van Duzen engine. Air, previously heated by the exhaust gases, is drawn upwards by the suction stroke of the motor piston into the vaporiser, a glass or metal chamber, above which is a tank containing light petroleum or gazolene. The current of air lifts a valve, and a small quantity of gazolene flows into the vaporiser, where it is said to be instantly turned into oil vapour by the hot air. The engine is vertical, and is made with two cylinders for larger powers.

Union.—In the Union horizontal engine, built by the same Company, the charge is also fired electrically, contact being made and interrupted between two electric wires by projections carried on the ignition and exhaust valve rods. The usual four-cycle is employed, and the valves are acted upon by cams from an auxiliary shaft. A weight governor is carried on the crank shaft, and if the speed is too great, the exhaust valve is held open, and at the same time the admission valve closed by a small beam. Only stationary engines of this type have hitherto been made.

Sintz.—The Sintz engine is made in sizes from 1 to 15 H.P. by the Sintz Gas Engine Co., of Michigan. Like the Nash it is a two-cycle motor, and closely resembles the Day; when driven by oil a small pump is added, worked from the engine, which injects a fine spray of light petroleum into the compressed air, as it passes from the enclosed crank chamber to the upper part of the cylinder. The charge is fired by electricity. The governor acts upon the stroke of the pump, and diminishes the quantity of benzine in inverse ratio to the speed. A boat driven by a Sintz engine was shown at Chicago in 1893. Motion was imparted by connecting the engine to the screw by a shaft and friction coupling, and a single handle served to regulate the quantity of oil passing to the cylinder, and the action of the screw in the water. The cooling water was sent to the cylinder jacket by a small pump driven from the engine, which was also used to pump out the bilge water.

The **Webster Manufacturing Co.**, of Chicago, showed at that Exhibition a vertical engine, to be driven either by gas or benzine. It is of the usual four-cycle type, with admission and exhaust valves on either side of the cylinder, driven from a valve shaft running at half the speed of the crank shaft. The valve shaft also actuates a small pump, which draws the benzine from a receiver in the base of the engine, and sends it in minute quantities to a cylindrical chamber at the side. Air is drawn through this chamber by the suction of the piston, and passes charged with benzine to the cylinder, where the mixture is compressed, and fired by a tube heated by a Bunsen burner.

White and Middleton.—An engine of the ordinary four-cycle type, for gas or benzine, is made by the White and Middleton Co., Baltimore, in sizes from 2 to 32 I.H.P. In this motor the valve shaft is replaced by spur gearing. Ignition is by a tube with a timing valve, the spindle of which is worked from the motor piston. Ports are also uncovered by the piston through which part of the exhaust products escape, the remainder are discharged at the end of the stroke through a valve worked by a rod and levers from the crank shaft, through a slide and cam. The same rod actuates the spindle of the gas valve. Both exhaust and admission are thrown out of gear by the governor, if the normal speed is exceeded.

Raymond.—The vertical four-cycle Raymond gas engine is made by the Case Threshing Machine Co., Wisconsin, with one cylinder in sizes from 1 to 20 H.P., two cylinders 4 to 50 H.P., four cylinders 60, 85, and 100 H.P. All the parts are enclosed in a cast-iron frame. The crank shaft is in the base, which also contains a reservoir of oil, into which the crank dips at each revolution. The rotary valves at the top of the cylinders are held on their seat by springs, and worked by spur gear from the crank shaft. The automatic ball governor regulates the quantity of the charge, but does not effect the proportions of gas and air, and the engine is said to work so well that there is scarcely 2 per cent. difference in speed, when the load is thrown on and off. An impulse every revolution is obtained in the two cylinder type, with four cylinders there is one impulse per stroke. The charge is fired by electricity, and the dynamos worked direct from the flywheel. The engines are fitted with a patent starting device, and all sizes can be started with ease. A large number are made in the United States.

The **Backus** is a small vertical engine, having the automatic admission valve below, and over it the exhaust, driven from an auxiliary shaft. There is no timing valve; the centrifugal governor on the crank shaft acts on the gas admission. The **Pittsburg** engine is made with two cylinders, giving an impulse every revolution. Electric ignition is employed. The admission of gas and air is effected through a piston valve, which always sends on the mixture to the cylinder in the same proportions; the governor acts by diminishing the quantity, not the quality of the charge, if the normal speed is exceeded.

CHAPTER XXV.

FRENCH OIL ENGINES.

CONTENTS.—Foreign Oil Engines—Lenoir—Simplex—Sécurité—Tenting—Durand—Forest—Niel—Merlin—Quentin—Le Robuste—Millot—Brouhot—Roger—Crouan—Various.

FOREIGN oil engines may be divided into motors driven by ordinary heavy petroleum, of 0·80 specific gravity, and those using volatile oil spirit or benzine, of 0·65 to 0·70 specific gravity. Such a classification does not exist in England where, except in the Yarrow spirit launch, the aim of oil engine makers is to utilise and evaporate, as completely as possible, heavy non-inflammable petroleum. The use of benzine is much restricted by law here; in Germany it pays no duty, while in France it is hardly more expensive than ordinary oil. On this point M. Durand remarks "that the use of heavy petroleum complicates the working of an engine by adding a vaporiser." Heavy oil cannot, he says, be completely evaporated, but must always leave an incombustible residuum, causing waste and clogging the parts. He thinks it "a mistake to attempt to distil the oil in the engine itself, when mineral essence, already distilled, can be obtained. By the use of heavy petroleum one of the principal advantages of internal combustion motors, that they can be started at once, is also lost, since from ten to twenty minutes are required to heat the vaporiser." Most German makers supply engines for working both with benzine and ordinary petroleum, and several French motors are driven by much lighter oils than would be allowed in England. Only a carburator of the simplest description is required with them, instead of a vaporiser, the heat of which must always be carefully regulated.

Lenoir.—To this motor a carburator has been added, in which light oil of 0·65 specific gravity is used. Fig. 129 gives a view of this engine working with carburetted air; the action is the same as in the Lenoir gas motor. The position of the carburator above the cylinder is near enough for the heat of the engine to keep the oil in a proper fluid condition, and counteract the cold of evaporation, but not near enough to convert the oil into vapour. Hence the use of lighter petroleum, which can be evaporated without much heat. The cylindrical carburator, at the top of the figure, is attached to the engine, and a very slow rotatory movement is transmitted to it, as shown, by a small strap and worm wheel, running at 4 revolutions a minute. The air is drawn into the carburator through a filtering vessel,

and the tube to the right in the drawing. When charged with petroleum vapour, it is carried off to the engine at the other side, the shape of the tube preventing any unevaporated particles of carbon from reaching the cylinder.

Lenoir at first divided the carburator or rotating cylinder into compartments filled with sponge or other porous substance impregnated with oil. It was found that the air charged with this volatile spirit soon became decarburetted, and the apparatus was consequently remodelled. In the cylinder now used, a number of small semi-circular troughs are set round the inner circumference.

Fig. 120.—Lenoir Petroleum Engine.

The bottom is half filled with gazolene, and as the cylinder rotates, the troughs pass successively through the oil, and fill themselves. Raised by the continued movement of the carburator, each in turn is emptied of its contents, which fall in a fine rain back into the oil below. Thus the cylinder is always full of pulverised gazolene, thoroughly saturating the air as it passes through. The carburetted air is then conveyed to the motor cylinder through a passage or bulb, in which metallic wires are fixed, to prevent the flame from shooting back into the carburator.

A series of careful experiments were made by M. Tresca on a Lenoir engine working with carburetted air. Two engines were tested, of 2 H.P. and 4 H.P. nom.; the density of the

oil used was 0·65. In the first the B.H.P. was 1·96, and consumption of volatile spirit 1·06 pint per B.H.P. per hour; in the second the B.H.P. was 4.15, and consumption of oil 1·14 pint per B.H.P. per hour. This motor is made single cylinder, in sizes from 1 to 12 H.P., and runs at 220 to 160 revolutions per minute. The Lenoir petroleum engine is also used for portable motors, in sizes from 2 to 8 H.P., and for boats from 4 to 18 H.P. with two cylinders, one above the other. A 3 H.P. engine driving a launch was shown at the Paris Exhibition, in which the consumption was said to be 0·88 lb. oil per H.P. hour. Fig. 130 shows an indicator diagram taken during Tresca's second trial.

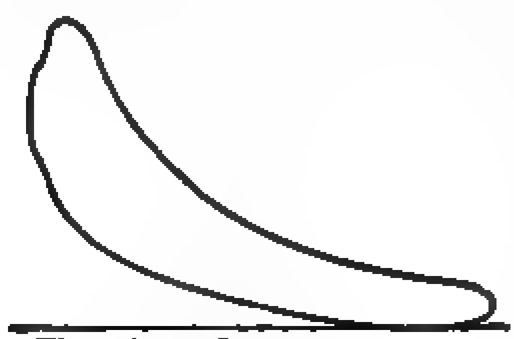


Fig. 130. — Lenoir Petroleum Engine—Indicator Diagram.

Simplex. — The Simplex gas engine of MM. Delamare-Deboutteville and Malandin, made at Rouen, and described at p. 135, has also been supplemented by a carburator. In this apparatus the density of the oil used is rather greater than in the Lenoir, but as the heat of the engine does not vaporise it, heavy petroleum cannot be employed. Fig. 131 gives a view of the Simplex carburator. R is the tank, usually open at the top to the atmosphere, and containing liquid petroleum of 0·65 to 0·70 density; D the valve for admitting it into the column E; B is a spiral horse-hair brush, which breaks the oil falling on to it into spray; at C is the casing round the column, heated by the hot water from the motor cylinder jacket. This water leaves the jacket at a temperature of 60° to 70° C., and falls to 40° or 50° C. by the time it reaches the carburator, where it helps to counteract the cold produced by evaporation. F is the small cock from which water, also drawn from the jacket, falls in a light shower into the column, and mingles with the narrow stream of oil entering

Fig. 131.—Simplex Carburator.

through D from R. The water helps to break up the oil into finer spray, and also to purify it, by holding in solution the coarser particles of dirt. The oil and water filter down through the spiral brush into the vessel L below, to which they are admitted through the valve V. Here the water and impurities are deposited at the bottom, and the water kept at a constant level by the overflow pipe N. The suction stroke of the piston draws air down from the top of the carburator through the column C, which is filled with oil spray and water, and this air, charged with petroleum vapour, is carriod off from the vessel L through the pipe S to the motor cylinder. A safety valve is placed in this pipe, to hinder the flame produced by the explosion of the charge from shooting back into the carburator. The hot water prevents all clogging of the valves by oil deposit, and the engine is found to work without trouble. As electric sparks are used in the Simplex engine, no difficulty is experienced in igniting the charge.

Sécurité.—A horizontal petroleum engine patented by MM. Diederichs (Belmont, Chabond, and Diederichs) and known as the "Sécurité," appeared at the Paris Exhibition of 1889. It is rather complicated, but is self-contained, and requires no external connections of any kind. Instead of an electric battery to fire the charge, the engine carries with it the ignition apparatus. This is an advantage in motors which are intended for use in the country, and to be handled by labourers. The "Sécurité" engine may be driven with any kind of petroleum, but the best for use is heavy mineral oil distilled from bituminous schist, of 0·82 to 0·85 specific gravity. For small powers lighter oil is required. Like the Priestman, it is not a gas engine adapted to the use of petroleum by the addition of a vaporiser, but has from the first been intended to work with oil.

Fig. 132 gives a general view of the engine. Two kinds of petroleum are used, both contained in separate compartments of the reservoir T. A lighter petroleum spirit is required to start the engine, and this is one of its drawbacks; after it is at work, ordinary heavy petroleum is used. A is the horizontal motor cylinder, and R the auxiliary shaft, worked from the crank shaft by bevel wheels 2 to 1. The engine stands on a strong foundation, B, which is hollow, and part serves as a reservoir for the compressed air. The shaft R works the ignition, admission, and exhaust valves by two cams and crank levers. One lever opens the admission valve under the cylinder as shown. The centrifugal governor G is also worked from R by means of bevel wheels, and regulates the admission of oil to the vaporiser by acting upon a cock, *r*, in the oil pipe. The petroleum for working the engine is contained in the front part of the reservoir T. From hence it passes through a small pipe, *p*, and the cock *r* to the vaporiser V beneath the cylinder, in which is a coil of pipes.

The exhaust gases pass into the vaporiser at E, and heat the petroleum, which in its passage through the coil becomes completely vaporised. It is then led out through a nozzle at the bottom, and injected into a pipe, F, leading to the admission valve of the cylinder. As it is already at high pressure and temperature, the suction of the oil spray jet draws in with it a current of atmospheric air from below the vaporiser at N, and the two become thoroughly mixed as they pass on to the cylinder. If the speed be too great, the balls of the governor rise, and act upon the pipe *p*, closing the cock *r*. No oil enters the vaporiser, and consequently only fresh air is drawn into the cylinder by the next out stroke of the piston.

The ignition apparatus is somewhat complicated, but has the advantage of requiring no battery, or gas to heat the tube. Petroleum essence, much lighter than the oil used for driving the engine, is contained in the vessel U above the cylinder. At P is the pump immediately below the crank shaft, and driven from it by an eccentric, through which air is pumped by the pipe *b* into a compartment in the hollow base of the engine, B, and from thence through b_1 to the vessel U. The hand pump C

Fig. 132.—Motor Sécurité—External View. 1889.

is used to compress the air into the reservoir when starting the engine. The pressure of this air in the vessel U forces the petroleum essence along the pipe *c*, past the cock c_1 adjustable

by hand, and it falls drop by drop into a current of compressed air conveyed in the branch pipe d from the air pipe b_1. The two are carried through pipe d_1 into the compression space M at the back of the motor cylinder A. Before reaching the burner, the highly inflammable carburetted air is heated by passing it through a small coil of pipes, d_2, kept at a high temperature by the heat from the cylinder. The burner consists of a small platinum capsule maintained at a red heat by a carburetted air flame. The charge in the cylinder, compressed by the back stroke of the piston, is ignited on reaching the capsule, and explosion and expansion follow. Communication is established between the cylinder and the igniting chamber M by a plug worked from the side shaft, which uncovers the small passage between them at every other revolution. The cylinder is kept cool by a water-circulating jacket, as shown. The consumption of oil is said to be about 1 pint per H.P. per hour. The engine is made single cylinder, horizontal, in sizes from 1 to 20 H.P., and runs at 240 to 150 revolutions per minute. The Paris agents are the Maison Albaret.

Tenting.—In this engine, described in the gas engine section at p. 155, a carburator of the simplest description is added to the ordinary motor. It is a cylindrical vertical reservoir divided horizontally into three parts; the volatile hydrocarbons are stored in the upper, and thence pass to the second chamber below it, which forms the carburator itself. Enough liquid can be carried in this reservoir for an ordinary day's work. The products of combustion from the cylinder are led through the lowest division, warm the carburator, and counteract the cold produced by the evaporation of the hydrocarbon liquid. The Tenting carburator is a good example of the method of carburating air by bringing it in contact with light hydrocarbon, without the application of much heat. Air, drawn in by the out stroke of the piston, is passed over the surface of the liquid in the central chamber. It enters on one side, and is carried off from the other to the cylinder, charged with the volatile petroleum essence. Driven with heavy petroleum this engine has now been adapted for portable work, and for road carriages and boats, when the lighter mineral essence is used. The charge can be fired either by electricity or hot tube, and for small sizes no water jacket is required, the cylinder being ribbed externally. The engine is made horizontal in sizes from ½ to 10 H.P., and runs at 200 to 160 revolutions per minute, vertical from 2 to 30 H.P. In the Paris trial of motor vehicles in 1894, the Tenting carriage ran from Paris to Rouen in seven hours.

Durand (1889).—Only the light volatile constituents of the oil are used in this engine, and the heavy hydrocarbons are allowed to accumulate at the bottom of the carburator, withdrawn and wasted. M. Durand thinks that there is in this

method a gain in power and smooth working, and that these advantages more than compensate for the slightly increased consumption of oil. Volatile petroleum being used, no vaporiser is required. The Durand carburator is fixed above the cylinder, the heat from which counteracts the cold produced by evaporation. By this arrangement the carburetted air descends only, and does not lose its inflammable properties, as it has been found to do when ascending. The level of oil in the carburator is kept constant by a float. Air is drawn through it automatically by the suction of the piston, and the float being weighted, the air passes always through the same quantity of oil, whatever the amount in the carburator. Thus the quality of the charge of carburetted air admitted to the cylinder is uniform. Electricity for the ignition is generated by a little magneto-electric machine, worked from the crank shaft. The two wires project into the cylinder, and their friction against each other keeps them clean. At a given moment they are forced asunder, contact interrupted, and a spark produced. The method employed is slightly different to that described at page 72, but the principle is the same. There are only two valves besides the automatic air valve, admission and exhaust, both driven by rods from the crank shaft; the ball governor acts upon the admission. The engine is well adapted for agricultural purposes, because it is complete in itself and requires no external light, or electric battery. It is made horizontal from ½ to 10 H.P., for portable engines from 2 to 10 H.P., and runs at 200 to 130 revolutions per minute. A peculiar feature is that it can be driven either with gas or light petroleum, as preferred.

Forest.—M. Forest, of Paris, has lately turned his attention specially to marine engines working with petroleum, and in conjunction with M. Gallice, has produced several motors, which attracted the attention of the French Government. One of their engines, of 30 H.P. with six cylinders, bought by the French Admiralty, was tested at Brest in 1890. Details of the trial will be found in the table at the end. A carburator on the Pieplu system is used, with light oil of 0·70 density. The surface of the petroleum is agitated by a rotating cylindrical brush. The air is drawn in by suction, and the petroleum being sprayed into it by the brush, it becomes charged with the evaporated liquid. A characteristic feature of these Forest motors is that they are reversible, rapidly started, and that the direction of the engine can be instantly changed. The marine motors have two or more vertical cylinders working downwards on the crank shaft. A distributing shaft, from which all the ignition and exhaust valves are driven, runs above the cylinders. This shaft has a double set of cams, one for working the boat forward the other for reversing the direction, and by slightly shifting the position of the cam to the right or left, one or the

other set can be brought into play. The charge is fired electrically, and the spark is produced or missed, according to the action of the ball governor upon the distributing shaft. The arrangements for rapidly changing the direction by reversing the engine depend on the adjustment of this shaft. Drawings of this ingenious motor will be found in Witz. All the latest engines are of the same type, vertical, with the crank shaft below, and the valves above. They are made with one cylinder from 1 to 6 H.P., two cylinders up to 8 H.P., and four cylinders for river motors up to 100 H.P., and run at 300 to 180 revolutions per minute.

Niel.—With the exception of the vaporiser, all the chief parts of this petroleum motor are similar to those of the Niel gas engine. There are two valves, one above the other, for the admission of the charge to the cylinder, and discharge of the exhaust gases; both are driven by cams and levers from the auxiliary shaft. Ignition is by a tube without a timing valve. As it is the end of the ignition tube furthest from the cylinder which is kept red hot by the lamp, the charge only penetrates to this hottest portion at the moment of highest compression,—that is, the outer dead point,—and is fired in the usual way. The oil used is of 0·80 density, and flows by gravity from a reservoir above, the level of which is kept constant by a float. From hence it passes partly to the vaporiser, partly to feed the lamp heating it and the ignition tube. The lamp consists of a small jet of oil vapour, issuing from the orifice of a pipe, which is always kept alight, and maintains a horse-shoe shaped tube over it at a red heat. Above is the vaporiser, a small cylindrical vessel with an outer jacket and internally-ribbed surfaces; the oil drops into the vaporiser from a hopper, the quantity entering at a time being regulated by a cock. Before starting, a little spirit is ignited in a shallow vessel below the lamp, and heats the tube and vaporiser, until sufficient vapour has been generated to make the lamp ignite spontaneously. The exhaustion of the spirit in the vessel should coincide with the attainment of a red heat by the tube and vaporiser. As soon as the lamp is started, the hot gases from it circulate through the jacket of the vaporiser, and keep it at a high temperature. The lamp is protected by a shield.

Air enters through an automatic valve, and carries the oil with it into the vaporiser, where it is evaporated, and the two pass to the valve chamber and cylinder through an admission valve. The valve shaft is driven half speed from the crank shaft. The flexible three-armed governor is the same as in the Niel gas engine. It is worked by an eccentric from the valve shaft, and acts upon the lever opening the exhaust, which is connected to that working the oil admission valve. If the normal speed is exceeded, the exhaust is held open, and the same action

23

suspends the movement of the oil valve. Thus the admission of oil is made to depend upon the opening of the exhaust valve.

A stationary and a portable Niel engine were exhibited at the Meaux trials. The water was sent to the jacket by a pump, but the quantity used was excessive, and the cylinder so much cooled that the heat efficiency was reduced. The consumption of oil at full power was 0·83 lb. in the stationary, and 1·6 lb. per B.H.P. hour in the portable engine. An official test was made on a 3 H.P. vertical Niel oil engine at the Agricultural Show at Montpellier in 1893, when the consumption of petroleum was 1·18 lb. per B.H.P. hour. Horizontal engines are made in sizes from $\frac{1}{8}$ to 15 H.P., and run at 200 to 170 revolutions per minute; vertical in sizes from $1\frac{1}{4}$ to 7 H.P., and run at 190 to 160 revolutions.

Merlin (1894).—This vertical oil engine is constructed by MM. Merlin et Cie., Vierzon, Cher, chiefly for agricultural purposes. Of the motors exhibited at Meaux it ranked among the best, both on account of the low consumption of oil, and of the high heat efficiency, as will be seen from the Table of Tests.

The engine somewhat resembles the Grob in its construction, and method of vaporising the oil. The vertical cylinder is above, the crank below, and between them is a valve shaft driven by wheels 2 to 1 from the crank shaft. The oil is contained in a receiver in the base, from whence it is drawn by a small pump, and sent drop by drop, as required, into the red-hot vaporiser. The latter is ribbed externally to afford a large heating surface, and kept hot by a lamp fed from a second small reservoir of oil, the pressure in which is maintained by an air pump. The exhaust valve and air and oil pumps are worked by cams and levers from the valve shaft. The oil injected into the vaporiser by the pump is pulverised by the air entering with it through a very small passage, and instantly evaporated by the heat. There is no timing valve, the vaporiser, which also acts as an ignition tube, being open to the cylinder. A larger current of air, admitted through an automatic valve lifted by the vacuum in the cylinder, enters from above, and mixes with the oil vapour drawn in from the vaporiser by the suction stroke of the piston. The charge is compressed by the next instroke, driven into the red-hot vaporiser, and ignites spontaneously. The governor consists of a weight and spring carried on the flywheel. If the normal speed is exceeded, it throws the whole valve shaft out of gear, the exhaust is held open, no oil passes to the vaporiser, and no vacuum being produced in the cylinder, the automatic admission of air is suspended. In the engine exhibited at Meaux, the water sent to the cooling jackets was circulated by means of a pump. As the action of the latter was checked by the governor if the normal speed was exceeded, the cylinder did not, as in other engines, become unduly cooled, and the heat efficiency was

consequently improved. The Merlin engine is made vertical only, single cylinder, in sizes from ½ to 8 B.H.P., and runs at 450 to 270 revolutions per minute. The consumption at the Meaux trials was very low—viz., 0·78 lb. oil per B.H.P. hour, and the heat efficiency 16·2 per cent.

Quentin.—This engine, made by MM. Quentin, at Valenciennes, for small powers, is intended principally for propelling boats, and also carriages to seat from 2 to 9 people. The oil used to drive the engine is rectified petroleum of 0·70 density, drawn from a carburator above, the level in which is kept constant. The carburator is not heated, nor is the air admitted to it under pressure, and a certain economy is, according to the makers, thus obtained. Ignition is by an electric spark. The horizontal engine has two cylinders side by side, and is cooled by water circulated from a pump; there are only two valves, admission and exhaust, and one governor regulates the speed in both cylinders. They are easily uncoupled and worked separately, if less power is required, and this is an advantage when the same engine is used for different purposes. It is made in sizes from 10 to 100 H.P., with a speed of 220 to 120 revolutions per minute. A single cylinder type is also made from ½ to 10 H.P., and runs at 300 to 180 revolutions per minute.

Le Robuste, made by the inventor, M. Levasseur, and described at p. 160, is worked with petroleum as well as with gas. This motor has no carburator. Ordinary oil is used, and the consumption is about 1 lb. per horse-power per hour. The oil is vaporised automatically in a vaporiser heated by a lamp fed from the receiver containing the oil for the charge. The engine is very strong, with no delicate parts; it is made horizontal only, in sizes from 1 to 7 H.P. nominal.

A vertical oil engine of the same type as the Merlin is made by MM. **Millot Frères**, at Gray, in Savoy. Heavy petroleum is used in this motor, which is said to require no external light or electric battery for ignition. There are two valves for admission and exhaust, driven by rods from the crank shaft, and acted on by the governor. The cylindrical vaporiser is at the top of the engine, the air enters automatically from above, as in the Grob. The engine is made in sizes from 1½ to 7 H.P., chiefly for agricultural purposes.

Brouhot.—The petroleum engine made by MM. Brouhot, of Vierzon, is similar to the gas engine described at p. 160, with the addition of an apparatus for evaporating the oil. This consists of a carburator, a large reservoir above it, and an intermediate receiver to regulate the supply of oil to the carburator. By means of the receiver, the level of liquid in the carburator is maintained uniform, and the air always charged to the same extent with volatile petroleum. The oil is pumped to the top of the carburator, and falls in its descent through a perforated screw;

the air as it passes upwards meets it, and becomes thoroughly carburetted. Electric ignition is used, and in other respects the engine does not vary from the usual four-cycle type. It is made vertical, in sizes from ½ to 3 H.P., horizontal, with one cylinder ½ to 10 H.P., with two cylinders 4 to 20 H.P. As a portable engine it has already obtained considerable success.

Roger.—The small vertical oil engines lately brought out by M. Roger are compact and very simple. The petroleum used is of 0·70 specific gravity, and is evaporated in a carburator placed at the side of the engine. Ignition is by a hot tube. These little motors are made from 1½ to 12 B.H.P., and run at 300 to 200 revolutions per minute; they are especially intended for manufacturing purposes and carriages.

The **Crouan** engine (see p. 160) requires no further description. The makers claim that it can be driven with gas or petroleum, as desired. If oil is used as the motive power, the engine must be connected to a carburator, and furnished with petroleum essence in the same way as with gas. There is no difference in the construction, nor in the sizes in which the engine is made.

Various.—Two small gas motors have now been adapted for use with petroleum, the *Noël*, made at Provins (Seine et Marne), and the *Delahaye*, at Tours. Both are for small powers, and intended chiefly for agricultural and manufacturing purposes. The Noël is constructed both horizontal and vertical, with electric ignition, in sizes from ¼ to 4½ H.P., and runs at 320 to 220 revolutions per minute; the smallest sizes have no water jacket. A portable engine type, 1 to 5 H.P., has also been introduced. The Delahaye is made vertical only, up to 40 H.P., and runs at 300 to 150 revolutions. MM. *Martini*, of Frauenfeld, in Switzerland, make horizontal single-cylinder engines, for use either with petroleum essence or ordinary oil. In the former, the receiver containing the supply of volatile oil is heated by the jacket water. Ignition is by electricity, as usual in engines using this inflammable essence. In the petroleum engines the oil receiver is placed above the cylinder, and the charge fired by a tube. The petroleum is admitted through a distributing valve, which regulates the quantity according to the power required. The engines are made in sizes from ½ to 25 H.P., and run at 240 to 150 revolutions per minute. The horizontal *Pellorce*, made at Courbevoie, and mentioned at p. 159, is also constructed for use with petroleum, in sizes from ½ to 6 H.P., and runs at 180 revolutions per minute.

The Griffin oil engines are made in France by MM. Crozet et Cie. at Chambon-Feugerolles (Loire), and the Grob by the Société Générale des Industries Économiques, Paris.

CHAPTER XXVI.

GERMAN OIL ENGINES.

CONTENTS.—Daimler—Adam—Altmann and Küppermann—Koerting—Langensiepen—Berliner Maschinen-Bau Gesellschaft—Kappel—Dürkopp—Seck—Benz—König Friedrich August Hütte—Butzke—Kjelsberg—Sachsenburger Maschinen Fabrik—Januschek—Bechstein—Hermann—Escher-Wyss—Bánki—Otto—Hille—Grob-Capitaine.

Daimler (1885).—This important little motor differs in some respects from the gas engine of the same name, described in the gas engine section. It has two single-acting cylinders, set ver-

Fig. 133.—Daimler Oil Engine. 1890.

tically or at a slight angle, and working upon the same crank shaft, but they have no valves. The sides and covers of the cylinders are cooled by water jackets. Fig. 133 shows the arrangement of the parts, Fig. 134 the method of vaporising

Fig. 134.—Daimler Oil Engine—Vaporiser. 1890.

the oil. The air, previously warmed by the hot gases from the lamp L (Fig. 133), is introduced in the direction of the arrows into the cylindrical upper part of the receiver A. This is divided into an outer and inner portion by concentric wire gauzes, and through the centre passes a tube conveying oil from the reservoir R into the lower part of A; the oil is kept at a constant level by means of a funnel-shaped float, B (Fig. 134). The hot air is drawn by the suction of the piston through the outer jacket of the upper cylindrical portion of A, and forced out at the bottom through the oil at L, its direction being regulated by the float. As the level of oil is kept the same, the air always passes through a layer of uniform thickness. The oil with which it is charged impinges against the plates H and F, and is broken up; part falls back into the reservoir below, and part is carried up with the current of air. The force of the air blast produced by the vacuum in the cylinder being always the same, and the level of oil constant, the latter is said to be completely vaporised. The mixture then passes through the wire gauze to the admission valve H, where more air is drawn in,—sufficient to make the charge inflammable,—and thence to the motor cylinder; the arrows indicate the direction. The two valves for admission and exhaust are placed one above the other in the same valve chest, and the lamp between them; thus the incoming charge is still further heated, before it passes to the cylinder through an automatic lift valve, as in the gas motor. The back stroke of the piston compresses the charge in the usual way.

Ignition is effected by means of two small external lamps, L (Fig. 133), one for each cylinder. These lamps are fed from the reservoir R, the valve cock *p*, and the receiver B; thus the reservoir supplies both lamps and vaporiser. The passage of the oil to the lamp is regulated by the valve V, and the lamps burn with a clear blue flame. Within them are fixed two very small nickel, platinum, or cast-iron rods, kept at a white heat, which fire the charge in either cylinder automatically, without a timing valve, at the end of the compression stroke. Upon the proper burning of the two lamps the efficient working of the engine in a great measure depends. The Daimler claims to be one of the first motors, if not the earliest, in which automatic ignition was introduced. The advantages of this method of firing the charge are that ignition is certain, and that it is bound to take place at the dead point. The arrangement, now found in several oil motors, was necessitated by the high speed at which the Daimler engines run, a speed so great that no valve gear could be relied on to give punctual ignition. At the same time, in this engine, the Capitaine, and others igniting the charge spontaneously without an ignition tube or timing valve properly so called, great care is needed to prevent premature

ignition, since the red-hot vaporiser is always open to the cylinder. The quantity of air first admitted to break up or spray the petroleum must be so small, that the charge is not inflammable till it has been mixed with a further proportion, and its temperature raised by the compression stroke. In all these engines special attention is paid to the admission of air, and the quantities are carefully regulated.

The exhaust valve in the Daimler engine is worked from the crank shaft by an eccentric, and all the other valves are automatic. The governor is on the flywheel. The speed is regulated by keeping the exhaust open if the normal number of revolutions is exceeded, and admission being automatic no charge can enter. Starting the engine is effected by means of a hand crank, which carries a wheel gearing in to another on the motor crank shaft. As soon as the engine is at work, its speed being greater than can be overtaken by the hand crank, the latter slips out of gear.

The Daimler motor works with petroleum of 0·68 to 0·86 specific gravity, and the cost is said by the manufacturers to be about 1d. per H.P. hour. Driven with oil, these engines are much used for carriages, boats, fire engines, pumps, &c., on account of their small dimensions and low consumption of oil; the quantity required being relatively small, a considerable saving is effected in the bulk of the engine, of special advantage in portable motors. The original type, with two cylinders set at an angle to each other, is used for portable and boat engines, the later type with vertical cylinders for stationary motors. The 2 H.P. Daimler engine exhibited at Mainz was 4·3 inches cylinder diameter, 6·3 inches stroke, ran at 510 revolutions per minute, and worked with petroleum of 0·70 density. The latest gas and oil engines have only one cylinder, and thus both price and weight are diminished. The engines are made vertical only, in sizes from ½ to 10 H.P. stationary, and run at 200 to 540 revolutions per minute, with one or two cylinders. For boats they are constructed with one, two, or four cylinders, with a maximum speed of 580 revolutions, and in sizes up to 25 H.P. The latest engines run at 750 revolutions per minute. (See Chapter on Practical applications.)

Adam (1893).—The Adam petroleum engine resembles the gas motor of the same name, already described, with the addition of a vaporiser. Benzine is used as the motive power, but instead of the air being passed through it, and saturated with volatile vapour, the inflammable gas is generated from the benzine by a benzine flame, and the ignition flame is also fed with it. The principle is similar to that of the oil vapour lamps, now generally used in petroleum motors, and the engine is said to be safer than most of those working with this light oil, because the explosive vapour is produced per stroke as required. The benzine flows from a receiver above, by gravity, into a hollow

cylindrical space between two tubes; in the outer tube a light is kindled before starting by a little spirit, and afterwards kept burning by a portion of the evaporated benzine. The main part of the oil passes into the inner tube, and down to a cylindrical receiver below, through a valve lifted by the suction of the motor piston. This receiver is surrounded by a jacket, into which air is admitted through an automatic valve. The benzine vapour passes through holes in the receiver, and mingles with the current of air on its way to the cylinder. The relative proportions of air and vapour for each charge can be regulated by altering the size of the receiver. The valves being automatic are lifted according to the pressure in the cylinder. As the inflammable vapour is generated per stroke, the quantity is very small, and unless the piston draws it off to the motor, it is not produced. The aperture through which the gases are carried off is exactly proportioned to the pressure, and the height of the feeding reservoir above the cylinder. The charge is ignited in the same way as in the Adam gas engine, by the descent of a cylindrical valve shutting off the flame. The speed is regulated by a ball governor acting on the exhaust. The admission and exhaust valves are so connected that, when the latter is held open by the governor, the admission valve is closed, and no fresh mixture can either be generated or enter. The engine is made in sizes from 2 to 10 H.P., vertical and horizontal, and runs at 230 to 170 revolutions per minute; it can also be worked with ordinary petroleum.

Altmann and Küpperman (1891).—This engine, made by Altmann & Co., of Berlin, is compact, simple, and has already met with considerable success, especially as a stationary or portable agricultural motor. In the original vertical type the piston worked upwards on to the crank. Admission, ignition, and exhaust were effected from a horizontal auxiliary shaft, worked from the main shaft by two sets of conical wheels. The petroleum was delivered by a small pump with adjustable stroke to the vaporiser, a shallow vessel heated by a spirit lamp, into the flame of which the hot ignition tube projected. The vaporised oil then passed to another valve chamber, where it was diluted with air before entering the cylinder. Here it was exploded and expanded, as usual in four cycle engines. The oil pump and the suction valve admitting the oil from the reservoir were worked from the same lever, by a roller and cam on the auxiliary shaft. If the engine ran too fast, the cam was thrown out of gear by the ball governor and missed the roller, and no oil entered the cylinder until the speed was reduced.

In the latest types of this engine (see Fig. 135) some modifications have been introduced, the parts simplified, and their number reduced. It is now usually made horizontal. No vaporiser, strictly so called, is used; the oil is drawn from the

reservoir and injected into a current of air, and the two pass through a mixing chamber to the admission valve, the heat of which is said to be sufficient to vaporise the oil. The chamber and valve are heated at starting only, and the makers consider it an advantage that the oil is not at a very high temperature when vaporised, because there is no deposit of tarry products. The admission and exhaust valves are driven by cams and levers from the valve shaft, and the governor acts upon the admission and the oil injection. The charge is fired by a nickel or porcelain tube. A novelty in the portable engine exhibited at the Berlin trials was that the compression space could be reduced in size when starting, and expanded to its full dimensions as the engine became hot. At these trials this was the most economical of all

Fig. 135.—Altmann Oil Engine. 1893.

the portable engines, and was highly commended, the consumption being only 0·83 lb. oil per B.H.P. hour. Stationary engines are made vertical from ¾ to 5 H.P., and run at 240 revolutions; horizontal from 2 to 20 H.P., with a speed of 240 to 200 revolutions per minute. Portable engines are made horizontal only, from 2 to 16 H.P., and run at the same speed.

Koerting (1890).—In the Koerting engine (see Fig. 136), when driven by benzine or ordinary petroleum, the oil flows by gravity from a receiver above, the air enters at the side, at right angles. Both are admitted through one automatic valve, and the oil is then sprayed or pulverised by drawing it down into the vaporiser between two discs, at the same time as the air current. The three processes of admitting the oil and air, and pulverising the former, take place simultaneously, and are in exact proportion to the pressure in the cylinder. The dimensions of the oil valve are so adjusted that the opening uncovered

when the rod is lifted is always less than the aperture, and thus the composition of the charge is maintained uniform. To counteract the vibrations of the automatic admission valve, a quieting piston is placed beneath it. The oil and air then pass to the vaporiser, which is kept at a red heat by the flame heating the ignition tube, the oil is evaporated, and the mixture admitted to the cylinder. The ignition tube has no timing valve, and is only red hot at its further end. Before the dead point is reached, a small valve opens communication between it and the outer air, and the products of combustion are discharged. The valve then closes, the fresh compressed mixture in the cylinder

Fig. 136.—Koerting Oil Engine. 1893.

comes in contact with the red-hot portion of the tube, and perfect explosion is said to be the result. The lamp for heating the vaporiser and ignition tube is so arranged, that the pipe conveying the oil to it is carried through the flame. It is kindled at starting by a piece of asbestos soaked in spirit, and afterwards by an ordinary wick fed with oil vapour. The exhaust is the only valve driven by gearing.

The speed is regulated, as in the gas engine, by a momentum governor acting on a knife edge. If the normal speed is exceeded, the governor interposes the knife below the lever opening the exhaust, and keeps it open. Since no compression

can take place, no charge is admitted. The automatic admission valve is connected to the valve shaft above by two springs. If, during the opening of the exhaust, the valve shaft is held fixed in a high position, the stronger of the two springs does not allow the automatic valve to rise, and the admission is cut off. For benzine or ordinary oil the Koerting engine is made from ½ to 30 H.P., and runs at 320 to 160 revolutions per minute. The larger sizes are horizontal, the smaller vertical.

Langensiepen (Lüde-Vulcan, 1891).—A petroleum engine constructed by Langensiepen, of Magdeburg, and designed by Herr v. Lüde, has been tested by Professor Schöttler. It is a horizontal four-cycle motor, self-contained, with hot-tube ignition. The admission, distribution and exhaust valves are worked by cams and levers. The exhaust lever is acted upon by a cam on the auxiliary shaft, parallel to the crank shaft, and driven from it by spur wheels; the same shaft works the oil pump and admission valve. The ball governor is fixed upon the crank shaft inside the driving pulley, and acts by cutting out the number of explosions. If the speed be too great, it pushes forward a projection, which catches in the lever of the admission valve; the valve is not raised, and no charge enters the cylinder.

The most original parts of this engine are the methods of conveying the oil to the vaporiser, and the lamp. The oil descends by gravity from a petroleum tank above the cylinder, and passes through the suction valve of the oil pump, worked by the auxiliary shaft, which also regulates the descent of the little plunger piston. The stroke of the pump is always the same, and delivers an equal quantity of oil, but the pump communicates with two delivery valves and pipes. One opens a passage back to the oil reservoir above. The other has a nozzle attached, through which a certain quantity of oil is injected, at every stroke of the oil pump, into the air valve. Air enters at the same time, the valve being worked by the same lever. The proportions of oil sent on to the vaporiser and motor cylinder, and returned to the reservoir, are determined by the adjustment of a screw in the plunger of the oil pump; the stroke is regulated by moving a handle. The oil being sprayed into the air, the two pass into the vaporising chamber below, communicating with the cylinder. At starting, this chamber is heated by a lamp fed from a second reservoir of petroleum spirit. As soon as the engine is at work, the heat generated by the explosions is sufficient to keep the vaporiser at a suitable temperature; the lamp on its stand is then drawn back a little, and serves to heat an ignition tube of the ordinary type, connected to the vaporiser. The lamp consists of a coil of pipes, in which the petroleum is converted into gas by the heat of the flame; the amount of oil passing into it at a time is regulated by a screw valve, and it is said to burn with very little carbon deposit. The engine runs

at a hign speed, making in the small $1\frac{1}{2}$ H.P. motors 600 revolutions per minute. In the motor tested by Professor Schöttler, the mean speed was 325 revolutions per minute. The engine indicated 6·7 H.P., and the consumption of petroleum was $\frac{3}{4}$ pint per H.P. hour. In the two engines exhibited at the Berlin trials, the oil and air admission valves were both automatic, and connected to each other; the oil flowed by gravity from a receiver above, and was sprayed by a current of air into the vaporiser. The governor acted on the exhaust. The consumption of petroleum was about 1 lb. per B.H.P. hour. In the portable engine, the pressure of the exhaust gases was utilised to draw a current of fresh air through the cooling water tank.

The same engine is made by G. Kühn of Stuttgardt, under the name of the "Vulcan." It was shown at the Frankfort Exhibition of 1891, and the author saw it working well at the high speeds given. The consumption of oil varies, according to the makers, from 1·1 lb. for engines of 1 to 2 H.P., to about $\frac{3}{4}$ lb. in engines of $5\frac{1}{2}$ to $6\frac{1}{2}$ H.P. These two engines are fully illustrated in *Zeitschrift des Vereines deutscher Ingenieure*, August 29, 1891.

The Berliner Maschinen-Bau Gesellschaft (late Schwartzkopff) were one of the earliest firms to bring out a petroleum engine on Kaselowsky's patent (see also the "Rocket" oil engine, p. 332). The vaporiser, which is shaped like a vertical tubular boiler, is at the side of the cylinder, and is heated at first by a lamp, afterwards by the exhaust gases. Petroleum is admitted through an automatic valve from a receiver above, and sprayed by a current of air into the vaporiser. The gases of combustion at about 752° F. pass through the tubes of the vaporiser, the petroleum circulates round them, and is completely converted into vapour before the gases are discharged. It is then conveyed to a chamber at the back of the cylinder, and mixed with more air in the admission valve. The charge is fired by a tube with a timing valve, driven, like all the other valves, by cams and levers from a side shaft geared two to one to the main shaft. The speed is regulated by a pendulum governor, which checks the admission of a fresh charge by closing the oil valve, if the normal number of revolutions is exceeded. Two of these engines were exhibited at the Berlin trials, where the consumption in an 8 H.P. engine was 1 lb. oil per B.H.P. hour. The motor is made horizontal only, in sizes from 1 to $11\frac{1}{2}$ B.H.P., and runs at 400 to 190 revolutions, with a piston speed of 495 feet per minute.

Kappel (1891).—This well-known firm makes engines to work either with petroleum or benzine, and exhibited an oil motor at Antwerp in 1894. In this engine the oil is conveyed from a receiver above to the vaporiser, through a small pump driven from the valve shaft. The pump acts during the explosion stroke, and thus time is allowed for the complete vaporisation of

the oil during the three following strokes. The vaporiser and ignition tube are heated by a small lamp, and are enclosed in a chamber at the back of the cylinder. In the benzine engines electric ignition is sometimes used, because of its greater safety. The exhaust and air valves and petroleum admission valve are all worked by cams from the valve shaft. The ball governor acts upon the oil valve, and closes it if the normal speed be exceeded, and also checks the admission of oil to the vaporiser. The oil pump carries two small pistons to send on the oil, which are driven to and fro in a slide from a small crank on the valve shaft. One piston moves with the slide, the other is partly free, and only acts during a portion of the stroke. By an ingenious arrangement the pistons draw the oil into the little pump cylinder, and press it out between them, when they come together, into the pipe leading to the vaporiser. The governor interposes a bar between these pistons if the engine is running too fast. Both then move solid with the slide valve, and no oil can enter. The engine is made horizontal, single cylinder only, in sizes from 1 to 12 H.P. for either benzine or ordinary petroleum, and runs at 230 to 150 revolutions per minute.

The Bielefelder Maschinen-Fabrik (Dürkopp) exhibited oil engines both at the Antwerp Exhibition and at Berlin. The consumption in the latter was 0·99 lb. per B.H.P. hour; in the portable engine the water in the jackets was circulated by a small centrifugal pump. Like the Kappel firm, these makers construct engines to be driven both with benzine and ordinary oil. Petroleum under pressure is contained in a receiver below the horizontal cylinder, and supplies the engine, the lamp for the hot tube, and the burner to heat the vaporiser at starting. The pressure is maintained by a small air pump driven from the engine, as in the Priestman. The oil for the charge passes cold through a sprayer into the red-hot vaporiser, where it is evaporated, and, after being mixed with air, is conveyed to the cylinder, the quantity passing to the vaporiser being regulated by a ball governor. The vaporiser is above the exhaust valve, and is kept hot after the engine is started by the exhaust gases, which are also carried downwards to heat the incoming air, before they leave the engine. The makers lay stress upon the fact that the oil is sprayed while cold, and complete combustion is said to be the result, because all the heavy carbons in solution are broken up, before the oil is subjected to the heat of the vaporiser. The engine requires no lubricant except at starting, in all other respects it is similar to the Dürkopp gas motor. It is made single cylinder, both vertical and horizontal, in sizes from ½ to 40 H.P., and runs at 240 to 170 revolutions per minute.

Molitor (1893).—A new oil engine has been brought out by Molitor & Co., Maschinen-Fabrik, Heidelberg. It is of the usual

four-cycle type, both vertical and horizontal. The oil is drawn from a receiver, the level in which is maintained uniform by a float in the larger engines, and a system of air tubes in the smaller; thus the quantity drawn into the cylinder by the suction stroke of the piston is always the same. The valves admitting the petroleum to the air passage, and the charge into the vaporiser, are driven by levers and cams from a side shaft, running at half the speed of the crank shaft. The admission valve is not solid with the levers working it, but connected by a spring, and the levers only prevent it from vibrating, otherwise it is automatic. In this way variations in the amount of air admitted are prevented, and the quantity is exactly proportioned to the pressure in the cylinder. Below the air passage is a little receiver, to carry off the oil refuse. Air is drawn in by the suction of the piston, and as the air valve rises before the oil valve, there is already a current of air in the admission passage, before the oil is injected. The ignition tube is heated by an external lamp, and has no timing valve, the compression of the charge producing the explosion. The exhaust valve is driven by cams and levers from the side shaft, which also carries the ball governor. If the normal speed is exceeded, the balls rise and throw the tappet opening the oil and admission valves out of gear. The latter being partly automatic, cold air is still drawn in, but in small quantities, as the valve is held on its seat by a strong spring. The engine is a modification of the Altmann, and is made single cylinder vertical, in sizes from 1 to 5 B.H.P., with a speed of 240 revolutions, horizontal, 5 to 12 H.P., running at 200 revolutions; and with two cylinders, horizontal, from 16 to 24 B.H.P.

Seck (Gnom).—This vertical oil engine, made at Oberursel, was exhibited at Erfurt and at Berlin, where it was commended for economy. As shown at Fig. 137, it resembles the Capitaine in several respects. The crank and motor shaft are below, and with the valve gear are enclosed in a chamber partly filled with lubricating oil. The cylinder is above, the piston acts downwards, and the air enters automatically from the top. The exhaust is driven from the crank shaft by an eccentric, on the circumference of which is a worm-wheel gearing into another of twice the diameter; the latter carries a pin, which opens the exhaust valve at every second revolution. The centrifugal governor, also on the crank shaft, drives a pulley which, if the normal speed be exceeded, causes a pawl to catch in the spindle of the exhaust valve, and holds it open until the speed is reduced. A pump worked by the engine sends the oil from a separate receiver into a small vessel above the cylinder. From hence it is drawn through an injector by the suction stroke of the piston, together with a current of air through an automatic valve, into the vaporiser at the side. The air and oil vapour then pass to

the compression space of the cylinder, where the charge is mixed with more air through another automatic valve, and ignited after compression in the red-hot, ribbed vaporiser, as in the Hornsby, Capitaine, and other engines. Special care is taken in this and similar motors that the quantity of air first admitted is insufficient for combustion, otherwise, the vaporiser being open to the

Fig. 137.—Seck (Gnom) Oil Engine. 1893.

cylinder, premature ignition might occur. The engine is made vertical only, in sizes from 1 to 15 H.P., and runs at 400 to 250 revolutions per minute.

Benz.—The Rheinische Gas-Motoren Fabrik at Mannheim exhibited a Benz four-cycle engine, driven by light petroleum or naphtha of 0·71 density, at Mainz in 1893. The naphtha is contained in a reservoir, heated in cold weather with hot water at starting, or by the exhaust gases. Air is drawn into the reservoir and through a layer of naphtha by the suction of the motor piston, and when charged with inflammable vapour passes through a safety valve to another valve admitting it to the mixing chamber. Here the carburetted vapour is diluted with more air, and the charge enters the cylinder through an automatic valve. At the end of the compression stroke it is fired by an ignition tube, heated by a small naphtha lamp. The admission and exhaust valves are driven by rods, cams, and levers from the crank shaft. The engine is governed by cutting out ignitions. If the usual speed is exceeded, the ball governor acts on the admission valve lever, and holds it closed, and air only is drawn into the cylinder, until the speed is reduced. As the engine is driven by light petroleum, no vaporiser is required. The consumption, as given by the makers, is about 1·1 lb. oil per B.H.P. hour, with a 4 H.P. engine. This firm have made a speciality of motors for road carriages. A 3 H.P. engine, running at 300 revolutions per minute, is sufficient to

drive a carriage seating four people. These little motors have no governor, the speed being regulated by the driver. Ignition is effected electrically from accumulators, and to economise space the cylinder is cooled by evaporating the water in the jacket. The Benz engines are made single cylinder horizontal, in sizes from 1 to 12 H.P., and run at 200 to 150 revolutions per minute (see the Roger carriages).

The **König Friedrich-August Hütte** oil engine, made near Dresden, is a horizontal four-cycle motor of the ordinary type, and was tested at Berlin. The oil is sent by a pump through a slide valve to the vaporiser, where it is completely evaporated. Air enters through an automatic valve, and passes with the oil vapour through a mixing valve, driven by levers and an eccentric from the crank shaft. Ignition is by a tube, and both ignition and exhaust valves are worked from the main shaft. The ball governor acts on the oil valve. Another small engine of the same type is made by Herbst, of Halle. Ordinary heavy petroleum is used to drive it, and the speed is regulated by a pendulum governor.

Butzke.—A small vertical 4 H.P. oil engine, made by the above firm at Berlin, and resembling the Seck in design and construction, was shown at the Berlin Exhibition. The oil is sprayed by a pump into a current of air drawn in through an automatic valve. The admission valve chamber is heated, like the ignition tube, by the exhaust gases only. This is said by the makers to be sufficient to maintain them at the required temperature except at starting, when a lamp is used. The governor acts on the oil pump, the admission valve is automatic, and the exhaust driven by gearing from the crank shaft.

The **Kjelsberg** (1889) petroleum engine, constructed by the Maschinen-Fabrik Winterthur, and MM. Nobel Bros., of St. Petersburg, was exhibited at Chicago, and also at the oil engine trials at Meaux in 1894. It is a carefully-designed single-cylinder motor of the four-cycle type, and is made in sizes from 1 to 25 H.P., both vertical and horizontal; it runs at 240 to 160 revolutions per minute. In the vertical engine the oil passes by gravity from a reservoir above through a pump to the valve chamber, the stroke of the pump regulating the quantity. The air is drawn in through an automatic valve lifted by the vacuum in the cylinder, which thus determines the quantity admitted. The speed of the air is sufficient to spray the petroleum, and the latter is also broken up by falling over a cone into the vaporiser below, a vertical cylindrical tube with a jacket through which the hot gases circulate from a lamp heating the ignition tube. As the gases ascend, while the oil is carried down through the vaporiser by the current of air, complete and rapid vaporisation is said to be obtained by means of contrary currents, a principle utilised in several German engines. The vaporised charge is

then admitted to the cylinder through a valve worked by levers and cams from the auxiliary shaft, the valve aperture being so adjusted that the mixture passes freely to the cylinder. Ignition is by a small brass tube without a timing valve, heated by a lamp which also heats the vaporiser, and is usually fed by a branch pipe from the main oil supply. The small orifice of the tube prevents ignition till the end of the compression stroke. The oil pump, admission, and exhaust valves are all worked by cams and levers from the lay shaft, revolving at half the speed of the crank shaft. The oil pump is connected to the admission, but acts for a shorter time per stroke, to ensure a sufficient supply of air through the automatic valve to break it up thoroughly. All the valves except the air valve are closed by springs. The ball governor is on the crank shaft, and acts upon the exhaust, holding the valve open if the normal speed be exceeded. At the same time a lever is shifted, the admission valve and oil pump are thrown out of gear, the automatic air valve does not act, because there is no vacuum in the cylinder, and no mixture enters.

The vertical engine exhibited at the Meaux trials gave a maximum of 5·21 H.P. on the brake, with a consumption of 0·84 lb. per B.H.P. hour, at a speed of 226 revolutions; the engine was commended for quiet running. Experiments made in St. Petersburg on a 3½ H.P. motor showed a consumption of 1·1 lb. per H.P. hour of oil of 0·82 density. Russian oil is used by preference in this engine, especially that of the Nobel brand. About 800 motors have been made (1895). The author has seen several of these engines at work.

The **Sachsenburger Maschinen-Fabrik** have introduced a horizontal petroleum engine (Böttger's patent), and a 6 H.P. motor was shown at Erfurt in 1894. It is of the usual four-cycle type, with exhaust and admission valves worked from an auxiliary shaft. The ignition tube, without a timing valve, is heated by a lamp which also maintains the vaporiser, placed immediately above it, at a high temperature. The valves admitting the oil and air to the vaporiser are automatic, but cannot rise until the compression valve (or valve through which the charge passes to the cylinder) is lifted by levers and cams from the side shaft. As soon as the vaporised oil, mixed with a due proportion of air, enters the cylinder from the vaporiser through this valve, the latter closes, and during the return compression stroke the charge is driven into the tube and ignited. The ball governor, upon the side shaft, opens the admission valve at each revolution of this shaft. If the normal speed is exceeded, it slips contact with the valve rod, and no charge either enters the cylinder, or is admitted through the automatic valves to the vaporiser. The engine runs at 220 to 180 revolutions per

minute, and is made with one or two cylinders, in sizes from 1 to 12 H.P.

The **Januschek** engine, made at Schweidnitz, to work with benzine or ordinary petroleum, was exhibited at Berlin, and at Erfurt in 1894. At the latter place it was driven by benzine, and the charge fired by an electric spark. In the smaller sizes the admission valves for oil and air are lifted automatically by the vacuum in the cylinder. The exhaust valve is opened by an eccentric from the crank shaft. Upon this eccentric the pendulum governor is also placed, which acts on the exhaust and holds it open, if the normal speed be exceeded. The exhaust gases are led through the benzine receiver, and provide the requisite heat for keeping it at a suitable temperature; the engine has no water jacket. In the engines driven with petroleum, the oil is vaporised in a chamber heated by the same lamp as the ignition tube. All the valves of the larger oil motors are driven by gearing; the governor checks the admission of oil if the speed is too great, by acting on a small pump. The piston of this pump, worked from the motor piston, alternately covers and opens communication with ports leading to the cylinder, and by its to and fro motion regulates the quantity of oil delivered per stroke to the vaporiser. By adjusting the governor, the speed of the engine can be varied while running. Some engines for large powers are made horizontal, and the air, oil, and exhaust valves driven by eccentrics. The pendulum governor acts upon the air admission valve, and throws it and the oil valve out of gear if the normal speed is exceeded. A vertical portable 2 H.P. and stationary 4 H.P. engine were shown at the Berlin Exhibition, in which the consumption was 1·47 lb. oil per B.H.P. hour. For further tests see Table of Trials. The engine is made horizontal and vertical, in sizes from 1 to 30 H.P., and runs at 400 to 240 revolutions per minute.

The firm of **Bechstein** in Altenburg exhibited three gas and five oil engines (Bernhardt's patent) at the Erfurt Exhibition in 1894. All were four-cycle motors, and differed little from the usual type. In the petroleum engines the oil is delivered from a receiver above to the vaporiser, through a pump driven from the exhaust valve shaft. The vaporiser is heated by the same lamp as the ignition tube. The speed is regulated by the governor, which throws the oil pump out of gear, and keeps the exhaust open, when the normal number of revolutions is exceeded. The engine is made vertical and horizontal, in sizes from ½ to 20 H.P., and runs at 180 revolutions per minute.

Hermann.—A horizontal oil engine of the ordinary four-cycle type was also exhibited at Erfurt, by MM. Hermann of Leipzig. Through a small pump, driven by a rod and wheel from an eccentric on the crank shaft, the oil is delivered to the admission valve, and sprayed into the vaporiser by a current of air drawn

in through an automatic valve at the bottom of the cylinder. The vaporiser and ignition tube are heated by a lamp. The exhaust is opened from the same eccentric, by rods and a cam acting on a roller. The speed is regulated by a pendulum governor on the admission rod. The rod carries a grip, which slides up and down and opens the oil pump, and the governor is held against it by a spring, the tension of which is regulated by the speed. If the normal number of revolutions is exceeded, the governor misses the grip, the pump is thrown out of gear, and at the same time a lever, also connected to the governor, holds the exhaust open. As soon as the speed is reduced, a projection on the rod causes both exhaust valve and oil pump to come into action again. The engine is driven with ordinary petroleum only. It is made horizontal and vertical, single cylinder, in sizes from 1 to 12 H.P., with two cylinders from 12 to 25 H.P., and runs at 300 to 180 revolutions per minute.

MM. Escher, Wyss, & Co. (1893), of Ravensburg and Zurich, exhibited two horizontal engines driven by ordinary petroleum at Mainz, in 1893. These motors have an oil reservoir in the base, where the oil for the charge and for heating the lamp is stored under pressure. The pressure in an air tube above the receiver is raised at starting by the motor piston to 6 atmospheres; the tube is then connected to the reservoir, and keeps the oil in the latter at a pressure of 1½ atmospheres. The oil passes from the reservoir to a receiver, and is thence drawn by the suction of the piston through an automatic valve and a nozzle into the vaporiser, together with a current of air from a vessel surrounding the exhaust. The quantity of air is sufficient to spray the petroleum, but not to make the charge inflammable. It then passes through another automatic valve into the ignition channel, where it is mixed with more air admitted through a valve, driven like the exhaust and ignition valves by cams from a side shaft, at half the speed of the crank shaft. At the end of the compression stroke the charge is fired. The entrance to the tube is usually closed by a piston rod, but 5° before the dead point is reached the latter is released by a cam on the side shaft, driven out by a small portion of the compressed mixture, the tube uncovered, and communication opened with the ignition channel. The ball governor, placed above the side shaft, holds the exhaust valve open and the admission closed, if the normal speed be exceeded. As no compressed mixture is formed, the piston of the ignition tube is not driven out, and the charge is not fired. The vaporiser and tube are both heated by the same burner, and an ingenious little lamp is used at starting, which can be made to burn either with a thick smoky or a clear blue flame. The process of starting occupies about twelve minutes. The consumption in this engine is said to be about 1·6 lb. oil per B.H.P. hour, and it runs at 180 revolutions per minute.

Bánki.—This vertical oil engine, constructed by Ganz & Co., Buda-Pesth, is of the usual four-cycle type. The same lamp heats the vaporiser and hot tube; the latter is open to the cylinder without a timing valve. The method of spraying the petroleum is original. In the mixing chamber, which also acts as a vaporiser, is a vertical screw, through the centre of which a small hole is pierced. The conical base of the screw abuts on the funnel-shaped termination of a tube filled with oil up to a level kept constant by a float. Air is drawn down through the central hole of the screw by the suction of the piston at each stroke, and the oil at the base is suddenly sprayed out on either side through a conical seat by the force of the air current, and thrown against the sides of the chamber. It is next broken up by another blast of air admitted at right angles, and vaporised

Fig. 138.—Benzine Carburator—Otto Engine.

by the heat, and the charge passes to the cylinder through a valve driven by gearing. As the quantity of oil sprayed per stroke depends on the air passing through the centre of the screw, and thus upon the vacuum in the cylinder, the composition of the mixture is said to be always uniform. The vaporiser is heated not only by the lamp, but also by the exhaust gases, which are carried through the upper part before discharging to the atmosphere. In the large motors several of these funnels and screws are used together. It has now been found possible

to dispense with the lamp after the engine is at work, the heat generated by the motor itself being sufficient for the vaporisation and ignition of the oil. It is made in sizes from 1 to 4 B.H.P. and runs at 200 to 400 revolutions per minute.

Deutz-Otto (1890).—The German firm at Deutz make two types for use with benzine of 0·70 specific gravity, one of which was exhibited at Chicago in 1893. A drawing of the carburator is shown at Fig. 138. The benzine is introduced through a filter into the receiver, which is heated by a hot-water jacket; in cold weather the exhaust gases are also carried through the bottom of the receiver, to warm it. The level of oil is maintained constant by the float. Air sucked in by the outstroke of the piston enters the receiver as shown, and is drawn up from the bottom of the liquid through a nozzle, to divide and saturate it as completely as possible. From hence the carburetted vapour is conveyed to the cylinder through a vessel filled with pebbles to cleanse it, and return and safety valves prevent the flame from striking back. A wire sieve is fixed in the air tube with the same object, and a cock regulates the pressure of air in the receiver. Mixed with more air drawn from the base of the engine, the charge is then admitted to the cylinder through an automatic valve, and the usual cycle carried out. Electric ignition is used, the spark being produced by interrupting the current from a small dynamo, by means of a cam on the distributing shaft. This method is much employed in Germany for benzine engines, on account of its greater safety with these inflammable gases. The benzine motor is made in sizes from 1 to 12 H.P. and runs at 230 to 180 revolutions per minute.

In the Otto petroleum engines, in which oil of 0·80 to 0·85 specific gravity is used, the lamp for heating the tube and vaporiser is fed by oil vapour from the receiver. The oil is drawn from a reservoir above, in which its level is kept constant, to the mixing chamber, where it is sprayed through a nozzle into a current of warm air. From thence the mixture passes to the vaporiser, a kind of cylindrical jacket over the ignition tube, is evaporated against the hot walls, and enters the cylinder through an admission valve driven by a cam from the side shaft, and acted on by the governor. In a vertical type lately introduced for use with petroleum or gas, there is neither side shaft, cams, nor wheels. No timing valve is required, the compression in the cylinder sufficing to determine the moment of ignition. All the valves are automatic except the exhaust, which is driven by an eccentric from the crank shaft. To prevent the valve opening at every revolution instead of every other revolution, an elastic membrane, acted on by the pressure in the cylinder, connects the exhaust valve to the eccentric. During the compression stroke the pressure sucks forward the membrane and the valve is held closed. In the latest Deutz type the oil is

injected by a pump, which regulates the quantity admitted to the vaporiser per explosion. This necessitates a second eccentric on the crank shaft, set in motion by a membrane in the same way as the exhaust valve. As this membrane allows the pump to work only in accordance with the pressure in the cylinder, there is no need to regulate the supply of oil by the governor, and the latter acts, therefore, only on the exhaust valve. In the 4 H.P. stationary engine exhibited at Berlin, the oil was drawn from a receiver, and all the valves were worked by gearing. The 10 H.P. portable engine had a pump, which sprayed the oil into the air coming through an automatic valve; the action of the pump and admission valve was governed by membranes. The consumption of oil was 0·96 lb. per B.H.P. hour, and speed 297 revolutions per minute. The Deutz firm make vertical petroleum motors, 6 H.P. for one cylinder, 12 H.P. with two cylinders, running at 360 revolutions per minute. The horizontal engines are in sizes from 1 to 12 H.P., with a speed of 230 to 180 revolutions per minute. Fig. 139 gives an indicator diagram.

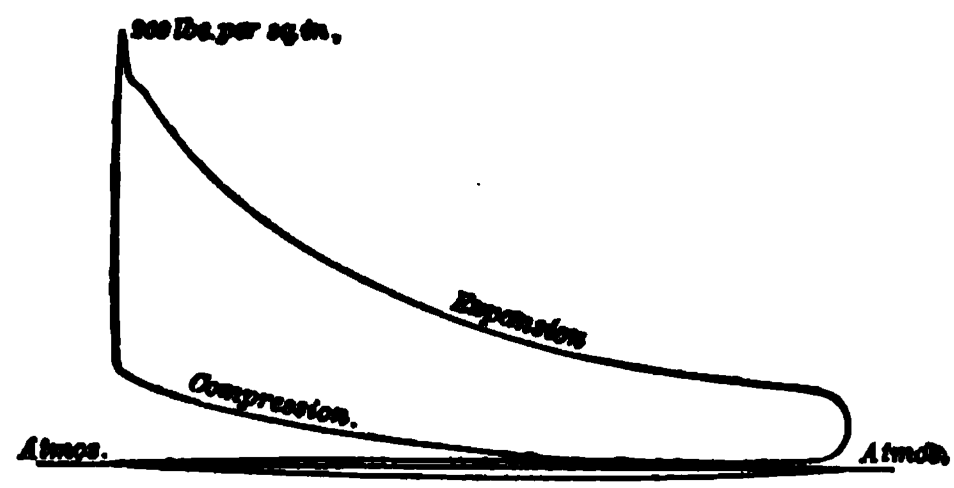


Fig. 139.—Otto Petroleum Engine—Indicator Diagram.

Several trials have been made on these engines. In 1892 Professor Teichmann tested a 2 and a 5 H.P. motor, running respectively at 227 and 215 revolutions per minute. The consumption of oil of 0·80 density was 1 lb. in the former, and 0·93 lb. in the latter, per B.H.P. hour. An important series of trials was carried out by Herr Meyer at Zurich in 1894 on a 4 H.P. Deutz oil engine. The air for combustion was measured by a meter, to which it was sent through a small fan driven by a turbine, as in Slaby's experiments. From thence it passed to the engine, its temperature in and out of the meter being taken. The quantity of petroleum, of jacket water, temperature of the latter in and out, temperature of the exhaust gases, and the volume of the cylinder and compression space, were all carefully determined. The object of the experiments was to ascertain the effect of the speed and of the richness of the charge,—that is, the amount of oil per stroke,—upon the work as shown by the indicator diagrams, and their influence upon the moment of explosion

and speed of flame propagation. To obtain the best results from the most diluted mixture in an oil engine, or, in other words, the maximum efficiency with the minimum consumption, Herr Meyer is of opinion that it is necessary (1) to introduce the petroleum into the cylinder in exactly equal quantities per stroke; (2) to vaporise the oil under the best conditions; (3) to bring a fresh and highly explosive mixture, undiluted with the burnt products, into contact with the ignition tube. For particulars of these interesting trials, see *Zeitschrift des Vereines deutscher Ingénieure*, August 17 and 24, 1895.

Hille (1893).—The Dresdener Gas-Motoren Fabrik (Hille's patent) exhibited several oil engines at Erfurt, in sizes varying from 1 to 8½ B.H.P., and a stationary and portable engine at Berlin. Like many other German firms, they make two classes of oil engines, for use with heavy petroleum and benzine. Ignition is by tube with the petroleum, and electricity with the benzine motors. In the former the oil falls from a receiver above to a double-seated automatic valve. As this valve is lifted by the pressure in the cylinder, it allows a current of air to enter, and carries with it the small valve admitting oil through a nozzle or holes into the valve chamber below. The latter, which also serves as the vaporiser, is placed immediately over the ignition tube, and both are heated by the same lamp. The charge of oil vapour and air pass thence to the cylinder through the admission valve, upon which the governor acts by a hit-and-miss arrangement, to regulate the speed. Usually the admission valve is opened from an intermediate shaft running at half speed, by a cam and levers which act on a collar and knife edge sliding up and down the valve rod. If the proper speed is exceeded, the governor brings another projection into play, and causes the knife edge to miss the opening of the valve. The admission and exhaust valves are held on their seats by springs, the exhaust being the weaker spring of the two. If the admission is held closed by the governor, the exhaust is automatically lifted by the pressure in the cylinder, and only burnt products are re-introduced until the speed is diminished. A second cam on the intermediate shaft holds open the exhaust during the compression stroke, when starting the engine.

In the benzine motor the volatile oil is vaporised in an apparatus similar to that in the Deutz-Otto engine, shown at Fig. 138. Air is drawn by the suction of the piston through a receiver containing benzine, the level in which is kept constant by a float, and passes to the engine saturated with oil vapour. The mixture requires to be further diluted with air before the charge is fit for use. Safety valves and wire gauze prevent the flame from striking back to the receiver, and the carburetted air is also drawn through a layer of pebbles on its way to the motor. The receiver is warmed by hot water at starting, and

Fig. 140.—Nuremberg-Lützky Oil Engine.

can also be heated by the exhaust gases, if necessary. The engine is made horizontal, for ordinary oil in sizes from ½ to 60 H.P., and for benzine up to 10 H.P., and runs at 250 to 150 revolutions per minute. The portable type is made from 2 to 12 H.P.

Lützky.—The benzine motor exhibited at Erfurt in 1894 by the Maschinen-Gesellschaft Nuremberg is the same as the Lützky gas engine, with the addition of a vaporiser. Contrary to the usual practice in motors working with light petroleum, the benzine is conveyed to the engine in a liquid state, and evaporated per stroke as required, instead of being used to charge the air in a separate receiver. This arrangement is said to be safer than the general working method. The vertical cylinder with crank shaft below is shown at Fig. 140. G is the ignition tube heated by a small lamp, L the admission valve; the benzine for the lamp and engine flows from a receiver above. The suction of the piston draws air through valve L from the pipe above, in the direction of the arrows. The small passages round the seat of the valve are always full of oil, but none can pass to the cylinder until the valve is lifted, when the pressure of air forces it forward. From thence it is injected through fine openings at *y* on to a small wheel with vanes, inside the mixing chamber, which being kept in rapid motion by the current of air catches the benzine as it falls, sprays it into the air, and thoroughly mixes them. The charge then enters the cylinder, and is compressed, ignited, and discharged in the usual way. The admission valve is worked by cams and levers from a side shaft, and acted on by a pendulum governor, which opens it or not, according to the speed. The exhaust valve shown to the right in Fig. 140 is driven in the same way. The governor consists of a fixed and a swinging lever. At ordinary speeds, a projection on the swinging lever fits into a cam on the side shaft, but if the engine is running too quickly, the swing of the pendulum causes the projection to miss, and the admission valve remains closed. As in the Nuremberg gas engine, there is a groove in the inner cylinder wall at *r* to catch the lubricating oil, carry it off to *f*, and prevent it from clogging the piston. In the 6 B.H.P. engine exhibited at Erfurt, the consumption of oil was 0·88 lb. per B.H.P. hour, cylinder diameter 6·7 inches, stroke 13 inches, and the engine ran at 190 revolutions per minute. It is made in sizes from 1 to 10 H.P., vertical only, single cylinder.

Capitaine (1888).—This important engine was one of the first to use common petroleum, and spontaneous ignition, or firing the charge by the heat in the cylinder only. The patents of the motor were originally acquired by Messrs. Grob & Co., of Leipzig-Eutritsch, who have improved it in several respects, and are said to have made the largest number of oil engines in Germany (3,000 up to 1894). Since 1891, M. Capitaine has

transferred his patents to M. Swiderski also of Leipzig, but the Grob firm have continued to make engines on the same lines, with a few slight modifications, and the engine is known as the Grob-Capitaine.

Like the gas engine of the same name, the Capitaine petroleum motor differs in some respects from others, especially in the care taken to stratify the charge as it enters the cylinder. The same

Fig. 141.—Grob-Capitaine Oil Engine. 1893.

four-cycle type and method of construction have been adhered to, as shown in Fig. 141. The diameter of the water-jacketed cylinder is larger than usual, and the stroke shorter. The admission ports are so designed that the charge enters at a high pressure, and is rapidly expanded. The compression chamber is conical. In both the gas and oil engine the exhaust

valve is worked by an eccentric on the crank shaft (compare Fig. 98, p. 188), and in the petroleum motor the oil pump to the right is also driven by an eccentric. To divide the wear of the gearing, a valve shaft, driven by wheels from the crank shaft, co-operates with the eccentrics in opening the exhaust and oil pump. The valve shaft acts upon the rod of the exhaust eccentric during the compression stroke, and prevents it from reaching the exhaust rod. It is only during the exhaust stroke that both act together, and rapidly lift the valve, the pressure being thus divided between the two cranks. The oil enters the suction of the pump by gravity, and is forced upwards by a small piston. The centrifugal governor is carried on the valve shaft. If the speed is too great the balls fly out, and a lever is interposed, disconnecting the oil-pump rod from the rod on the valve shaft actuating it (see Fig. 141). The small angled lever maintains the valve rod in position until the normal speed is resumed, and the pump again acts. Great care is taken, especially in the latest engines, in adjusting the contact of the governor with the levers.

Above the lamp, at the opposite side of the cylinder to the exhaust, is the vaporiser, in which the charge is fired, a small bent iron tube, occupying the same position as the ignition tube B, Fig. 98. As it is open to the cylinder without a timing valve, and the air is admitted automatically, there is the risk of premature ignition, minimised in this engine by the high speed at which it runs. Instead of admitting the air in two separate quantities, first to break up the oil, and a larger amount to render the charge inflammable, the whole enters the cylinder at once, being drawn from the base of the engine through the automatic valve at the top. It is then divided, part passes direct to the charging or clearance space, part is directed by a projection in the neck of the admission passage into the U-shaped tube of the vaporiser. The entrance to the latter is shaped like a nozzle, and here a minute quantity of oil from the petroleum pump is injected into the current of air and sprayed, carried with much force through the red-hot vaporiser, and completely vaporised. The speed of the air and the heat of the vaporiser cause all the petroleum to be evaporated, and there is said to be no heavy deposit. The oil vapour and air issue from the lower end of the U-tube, and with the rest of the air are compressed by the return stroke of the piston, driven up against the red-hot walls of the vaporiser, and fired. Thus it is the heat generated by the compression stroke, and the addition of air, which make the charge inflammable. The currents of air are said to form a non-explosive layer, and to prevent the oil vapour in front from communicating with the red-hot vaporiser until, in the return stroke, the dead point is reached. Herr Capitaine maintains that all the heat is employed to vaporise and ignite the charge,

and both vaporisation and combustion are therefore more complete. Owing to the stratification of the oil vapour and air, the top of the piston is hotter than the bottom, heat is said to be imparted to the charge during expansion, and raises the pressure curve. The indicator diagrams appear to confirm this theory.

The temperature of the vaporiser is maintained by a lamp beneath it, fed with oil from a receiver. This lamp is provided with a long bent tube, at the end of which is a conical burner; the flame of the burner not only evaporates the oil in the vaporiser, but in the tube. In the earlier oil engines the flame also played upon the small ignition tube. Firing by tube has now been discarded, and the heat of the vaporiser alone is found sufficient to ignite the charge, after compression. It was accidentally discovered that, after running some time, the Capitaine engines would work as well without as with a lamp, and in the latest Grob motors all external lamps are dispensed with, except at starting. The same arrangement was seen in the engines exhibited by Swiderski at Antwerp in 1894. In these motors the vaporiser has a ribbed external surface and inner projections. In place of the chimney are two iron capsules with asbestos joints. If the vaporiser becomes too hot, these expand and allow the external air to enter, and act upon the surface of the vaporiser. The temperature of the vaporiser is also sometimes made to regulate the flow of oil to the lamp. The cover of the vaporiser is held against it by a spring, and on the slightest expansion, due to overheating, the spring acts upon a membrane valve in the oil admission pipe, and checks the supply. To start the engine the exhaust valve is held open during the compression stroke, and the flywheel turned with a hand crank, which falls out of gear automatically when the engine is at work. Care is required because, when the engine is running slowly, the tube being open, ignition may occasionally take place before the dead point, and the crank turn in the wrong direction.

The Capitaine engine has been shown at most Exhibitions of late years, and was one of the best of those at the Berlin trials. Two vertical portable engines were exhibited at Berlin, the larger was of 7·12 B.H.P., and consumed 1·2 lb. petroleum per B.H.P. hour. In a trial of a 10·5 B.H.P. engine at Leipzig, in 1893, the oil consumption was 1 lb. per B.H.P. hour. At Meaux, a vertical Grob engine was shown, in which the consumption was 0·93 lb. per B.H.P. hour. The engine is made vertical, single cylinder, in sizes from ½ to 10 B.H.P., horizontal from 10 to 25 B.H.P., and runs at 500 to 180 revolutions per minute. For boats, two cylinders are used. It is also largely made as a portable engine, for pumps and many other purposes.

Grob.—The latest Grob engine is double acting with gradual combustion, on the principle of the Brayton petroleum motor.

The cylinder is arranged as in a valve steam engine, with an air compression pump behind it. To each admission valve a vaporiser is attached, in which the charge is ignited at the moment of vaporisation, and thus all loss by deposit of oil vapour is said to be avoided. The consumption is said to be only 0·46 lb. oil per H.P. hour. The author regrets that details of this interesting new engine are not yet sufficiently complete for publication. A drawing will be found in Lieckfeldt, p. 91.

CHAPTER XXVII.

PRACTICAL APPLICATIONS OF GAS AND OIL ENGINES.

CONTENTS.—Electric Lighting—Waterworks—Tramways driven by Gas—Dresden—Dessau—Tramways driven by Oil—Boats for Rivers and Lakes—L'Idéale—Capitaine—Daimler—Roots—Portable Engines—At Berlin—Meaux—Cambridge—Road Motor Carriages—Daimler—Roger—Tenting—Other Applications.

A GREAT impulse has lately been given to industrial development by the applications, to many purposes, of engines driven by lighting and power gas, and by oil. The advantages of these motors over steam for small powers, or where motive force is only required intermittently, have been already considered. It remains to notice the uses to which the power thus obtained has been applied, and these are so many and varied that the extensive utilisation of gas and oil engines will probably effect a great change in our present system of generating power. Hundreds are now sold every month, whereas a few years ago they were counted only by tens. One disadvantage of oil engines is, however, their very disagreeable smell, and inventors should turn their attention to this important point, which is greatly against the use of these motors in buildings and enclosed spaces.

Electric Lighting.—The competition of electricity with town gas as a means of illumination threatened the prosperity of the gas companies some years ago. Since, however, motive power is required to generate electricity, and is conveniently obtained by driving the engines and dynamos with lighting gas, this method of utilising the output of gas was adopted by many companies, especially on the Continent. The advantages of thus producing electricity are many. As it is usually required only during a certain number of hours in the twenty-four, the production may be intermittent, and the engines stopped for a time without

incurring any cost, as with steam. Or the gas may be utilised for other purposes during the day, as is often done in country houses, where it furnishes the motive power for pumping water, sawing, threshing, and other agricultural operations, and after dark the engines are coupled to the dynamos. In some towns abroad, as at Lille, where electricity is generated from engines driven by town gas, the consumers are allowed to light their houses by gas or electricity at will. Although a means is thus found of utilising gas, this method is not as economical as where the engines are driven by cheap or power gas, such as Dowson or Lencauchez, and in many large towns abroad the latter system has been adopted.

The electric light station driven by town gas, set up at Dessau in 1886, was probably one of the first; these plants are now widely distributed. A description of the new large electric station at Belfast, driven by Griffin engines and town gas, will be found at p. 111, and the Simplex engine is also used for this purpose. A novel arrangement has been adopted at Winterthur and other towns on the Continent, where, from the same gasworks, cheap power gas is supplied to consumers during the day for driving engines and heating purposes, and ordinary lighting gas at night, the same gas mains furnishing heat, light, and motive power. One of the largest stations in France is at Rheims, where electricity for lighting the town, &c., is provided by five Niel engines, two of 50 H.P., two of 80 H.P., and one 45 H.P., driven by town gas. An important test has lately been made by Professor Witz on an electric lighting plant at Roubaix, where the electricity is generated by two Tangye single cylinder engines, of 28 and 36 I.H.P. respectively. Details will be found in the table.

Waterworks.—The application of gas engines on a large scale to waterworks has been already noticed. In England there are several water-pumping stations worked by engines driven by Dowson gas. The largest are two 20 H.P. Crossley-Otto engines at the County Asylum, Gloucester. At Godalming Waterworks there are two 18 H.P., at Ross (Hereford) a 30 H.P., and at Teignmouth two 16 H.P. Crossley engines, all driven by Dowson gas. The Uxbridge pumping station, worked by Atkinson engines, has been mentioned; at Kenilworth the power is generated by a 20 H.P. Clark engine. Other smaller applications are at Wellington, Stevenage, and the latest at Marlborough, in all of which Crossley-Otto motors are used. There are also many stations in England where gas engines are used for pumping sewerage. Messrs. Crossley have put up two 40 H.P. and two 60 H.P. sewerage-pumping gas engines for the London County Council. Messrs. Tangye have also erected many pumping engines for waterworks, sewerage, and drainage, both for small and large powers, and especially a plant of several

120 H.P. engines at the Sunderland Docks, with pumps each discharging 2,600 tons of water per hour. At Laval, in France, power for the waterworks is generated by a 60 B.H.P. Simplex engine, driven by Lencauchez gas. But it is in Germany that the system has been most widely applied, and the water supply in small towns much improved in consequence.

Engines for pumping water may be divided into four classes, according to their motive power, whether driven by lighting gas, power gas, petroleum, or by benzine or volatile oil (on the Continent). In compactness, economy, absence of a chimney or boiler, and small attention required, they all possess great advantages over steam. Another recommendation is, that if the water pumps are worked by engines using town gas, not only are the gas companies benefited, but the output is equalised, more water and less gas being required in summer, while in winter the proportion is reversed.

The first waterworks in Germany driven by gas engines were those of Düren, in 1884, and other towns have not been slow to follow. The power was transmitted to the pumps through wheels, but pulleys and belting are now generally used. In engines driven by generator or power gas, in towns already supplied with lighting gas, as at Basle, gas coke can be utilised; but it is usual also to connect the engines to the gas mains, that they may be started quickly and easily in case of emergency. In smaller towns where there is no gas, and not much power is required, petroleum or benzine may be employed to drive the pumping engines. With benzine, as with lighting gas, the engine can be started without previous heating, but its use is prohibited by law in England.

The following table, compiled from data in the *Zeitschrift des Vereines deutscher Ingénieure*, March 16th, 1895, gives particulars of the principal towns in Germany where the waterworks are driven by Otto gas or oil engines, chiefly by straps or ropes. There are also four towns in which the water is pumped by Koerting gas engines.

The actual consumption in these engines varies considerably with the height to which the water is raised, &c., but the following is about the maximum and minimum :—

1 lb. gas coke will raise from 4,750 to 7,000 lbs. water to a height of 131 feet.

1 cubic foot lighting gas will raise from 310 to 560 lbs. water to a height of 131 feet.

1 lb. oil or benzine will raise from 7,500 to 12,000 lbs. water to a height of 131 feet.

Tramways Driven by Gas.—The use of gas for driving tramcars is one of the most promising applications of motive power, and appears capable of great extension. The Lührig system is that most generally adopted at present. The gas is

OTTO GAS AND OIL ENGINES USED IN GERMAN AND OTHER WATERWORKS.

Water Raised.		Revolutions per Minute.		Size of Pumps.	
Gallons per Hour each Engine.	Height. Feet.	Engine.	Pumps.	Diam. Inches.	Stroke. Inches.
27,720	180	140	30	10¼	30
26,400	190	140	25	10¼	31·5
33,000	148	130	30	11·0	20·5
46,000	154	140	28	13·1	31·5
7,000	197	180	72	5·1	11·8
5,500	287	180	75	4·5	11·8
6,620	150	180	75	4·0	11·8
12,450				5·5	11·8
22,000	305	150	75	6·2	15·7
31,800	82	160	75	8·8	11·8
22,100	148	170	75	7·3	11·8
25,000	177	140	30	9·8	27
79,560	308	140	00	10·2	27·5
4,000	295	180	70	4·3	11·8
5,570	170	200	75	5·0	11·8

drawn from a main, compressed by a fixed gas engine to the required pressure, and the reservoirs of the trams are charged with it. One advantage of this method of providing motive power is that in most towns where tramways are used, a gas main is always available. In the opinion of the best authorities, among them Professor Kennedy, F.R.S., tramcars driven by compressed gas are likely to be much used in the future, as they possess the further merit of being self-contained, and carrying with them a store of motive power, sufficient to last for a considerable time. Steam tramways are rather noisy, and the exhaust is sometimes objectionable; electrically propelled cars require overhead wires or other methods of conveying electricity, while the greater expense of horse-drawn cars has long been recognised. The relative cost, as given by Mr. Corbett Woodall, is one penny per mile for tramways driven by compressed gas, twopence per mile with electricity, and fivepence per mile for horse traction.

In gas propelled cars the power is also transmitted direct from the engine to the axles of the carriage, and there is less loss in transmission, than with electric traction. Gas tramways in large towns equalise the consumption of gas, as they run more in the day than at night, and oftener in summer than in winter. No central gas station is required, since the gas can be taken from the street mains and compressed at any point on the route. Great improvements have already been made in gas traction, and difficulties arising from noise, vibration, and smell have been much diminished. Objections have been raised to carrying a store of compressed and inflammable gas, but the same would apply to the compressed gas which has for years been extensively used on railways for lighting the carriages.

In gas tramcars from 6 to 10 reservoirs for the compressed gas are required, containing from 44 to 88 cubic feet. They are placed beneath the floor of the carriages, and charged with a supply sufficient to run the cars about 8 miles. About 8 per cent. of the total quantity of gas consumed is used to drive the fixed engine for compressing it. An 8 H.P. engine will compress 2,100 cubic feet of gas per hour to a pressure of about eight atmospheres. The charging of the reservoirs through an ordinary indiarubber tube takes about a minute and a half.

There are two systems of propelling cars by compressed gas, that of Guilliéron and Amrein at Neuchâtel in Switzerland, and the better known Lührig system, adopted both in England and Germany. At Neuchâtel the tramway is worked by an 8 H.P. gas engine, and the receivers carry sufficient gas for the double journey, 3 miles each way. The consumption is 34 cubic feet of gas per car mile. The Lührig gas traction system, invented by the late Herr Lührig in 1893, was first adopted at Dresden in March, 1894. The principle is that of connecting the engine

to the carriage by means of friction coupling, controlled by the driver. The carriage can be stopped without stopping the engine, by putting the clutches in or out of gear. Professor Schöttler gives a description, with diagrams, of the Lührig system of transmission in the *Zeitschrift des Vereines deutscher Ingénieure*, August 24, 1895. There are three shafts, each connected to the motor shaft by levers, and carrying wheels of different diameters. By shifting the levers, one or other shaft and set of wheels are thrown in or out of gear. The motor is a double cylinder 9 H.P. Otto engine, placed at one side of the carriage under the seat. The gas is ignited electrically, and thus no open flame is carried. The engine and car are worked from the front by the driver. When the car is stationary for a short time the engine is disconnected, and the supply of gas almost cut off, one cylinder being thrown out of gear, and an explosion only taking place in the other at every eighth revolution. By moving a lever a friction clutch is brought into play, connecting the engine shaft with the axles of the car, the supply of gas is partly turned on, and the car runs at a speed of 4½ miles an hour. If the lever is shifted to a third position, the full quantity of gas is turned on with a friction clutch of larger diameter, and the speed increased to the maximum of 9 miles an hour. For backing the car another lever reverses the action of the engine. The gas is carried in three cylindrical reservoirs, and a fourth holds the cooling water; the latter is placed on the roof of the carriage, beneath an upper tier of seats. The water descends by gravity to the cylinder jackets, and after cooling them circulates through tubes exposed to a current of air produced by the onward motion of the car. In all gas or oil engines used for propelling cars, portable engines, road carriages, &c., the arrangements for cooling the water form an important feature. The cars at Dresden hold 36 passengers, and the power of the engine can be increased if necessary to 12 H.P. The consumption was at first 36 cubic feet of gas per car mile, but this has since been reduced, and the cost is now about ½d. per car mile.

The gas tramway at Dresden was so successful that another plant was laid down at Dessau, in November, 1894, with similar carriages and engines. The line is nearly 3 miles long, and the supply of compressed gas is sufficient for a distance of 8 miles. The consumption of the two cylinder 10 H.P. Otto engine is about 29·8 cubic feet of gas per car mile. The engine and machinery are carefully protected from dust. As the town was already lit by electricity, it was originally intended to have an electric tramcar, but when it was found that an additional station would be necessary, the decision was taken to utilise the gas from the mains, and two gas compressing stations were erected, one at either end of the line. The average speed of the Dessau tramway is about 7½ miles an hour. Professor Kennedy made

a careful study of it, and reported so favourably that an experimental line was laid down between Thornton Heath and Croydon by the Gas Traction Company. The system is the Lührig, as at Dresden and Dessau, and the tramcar runs at a speed of about 7 miles an hour.

Tramways Driven by Oil.—A tramcar of a different type is used on part of the Croydon tramway line, and at Bermondsey. It is worked by a Trusty-Connelly motor driven by oil, and the transmission gear differs somewhat from the Lührig. In some respects oil ought to be superior to gas for traction purposes, since it does not require compression, and a larger supply can be carried on the car. Hitherto, however, petroleum as the motive power for propelling tramcars has not found as much favour as gas. This is probably due to the fact that tramways are chiefly required in towns where a supply of gas already exists, with mains close at hand, and the process of compression is simple and easy. In England only the two lines at Croydon and Bermondsey are worked with oil, but in the United States the Connelly motor has met with great success, and it is used on several of the Chicago tram lines. Whether the smell is found troublesome or not, we do not know.

The engine is a four-cycle 12 H.P. Trusty oil motor, with two vertical cylinders giving an impulse every revolution alternately in either cylinder. The charge is fired automatically by electricity from accumulators; the dynamo for charging them is driven by a strap from the engine, and the electricity from the accumulators also serves to light the carriages. The oil is carried in a tank on a roof of the carriage, which holds 14 gallons, or sufficient for the whole days' run of 72 miles. The engine car is self-contained, the two motor cylinders being in the centre, and the oil tank above. There is no water reservoir, properly so called, the water for cooling the engine being first pumped into the cylinder jackets, from thence to the oil tank, round which it circulates and imparts sufficient heat to vaporise the oil, and thence flowing into a nest of tubes beneath the carriage. These tubes being exposed to the atmosphere, the water is effectually cooled, and a continuous circulation maintained. The chief peculiarity of the Connelly motor is the transmission gear. The difficulty in this class of engine is to adapt the unvarying speed and (usually) irreversible action of a gas or oil motor to the varying speeds required in a tramcar. The traction gear here used gives a wide range of speed, and, in inverse ratio, of tractive power. This is effected by a transmission disc 30 inches diameter, set vertically to the crank shaft, and a loose friction pulley engaging with the face of the disc. The pulley is actuated by a shaft controlled by the driver, and according to its position, and contact more or less close with the disc, the speed of the engine is regulated. As the action of the engine

cannot be reversed, clutch gear is used, either to drive it forward at the end of the run, or in the opposite direction. The Connelly motor working at Bermondsey was examined and well reported on by Professor Unwin and Mr. Comrie. A tramcar worked by a Daimler oil engine was exhibited at Chicago.

Boats for Rivers and Lakes.—A cargo boat, the "Idéale," one of the latest applications of the Simplex engine, is now plying between Havre and Paris. This vessel is 98 feet long, 18 feet wide, and of 300 tons burden. It is worked by a 40 H.P. two-cylinder Simplex engine, driven by gas previously compressed to 100 atmospheres. The vertical pistons are set at an angle of 90°, and act downwards upon the shaft of a reversible screw on the M'Glasson system. Upon this shaft is a flywheel for starting, and gear for disconnecting the screw from the engine. The valves and exhaust are worked from an auxiliary shaft. The compressed gas is stored on the bridge of the vessel in tubes, similar to those used for compressed oxygen in England. From hence it is drawn as required, the pressure reduced to the proper strength for the charge, and the gas mixed with air in a separate chamber. The engine is easily stopped, can be started in one minute, and one man is sufficient to drive it. The station for compressing the gas is situated between Havre and Paris. It is stored in fixed reservoirs, and from them temporary pipes are connected to the tubes on board the vessel. Fig. 142 gives a sectional view of the engine, screw shaft, and transmission gear.

It is, however, with oil engines that the greatest progress has been realised, in applying this kind of motor to boats and launches. The *Capitaine* oil launch was perhaps the earliest in the field, and is now well known and much used. It was introduced into England, and a launch was tested at Chester in 1891. By means of a handle attached to the gearing the motion of the boat could be reversed or suspended. This launch was 35 feet long by 6 feet 10 inches, and carried 50 passengers. The 6½ H.P. engine made 240 revolutions per minute; the boat went at 8½ knots per hour. A 6 H.P. engine, propelling a small boat, was exhibited at Chicago, in which motion was transmitted from the engine to the screw shaft by a small rod passing through the centre of the horizontal screw shaft, and ending in a 3-armed lever. One or other of these arms engaged in the crank-shaped termination of the screw, and drove the boat either forwards or backwards. As in the tramcar engines, the motor is not stopped with the boat, but simply disconnected. There are usually two vertical cylinders in the centre of the vessel, with the oil reservoir under the bow, and a connection to the boat screw shaft at the stern. The exhaust gases sometimes escape through a chimney in the middle of the boat, sometimes they are carried along the side, and discharged at the stern. The pressure of air

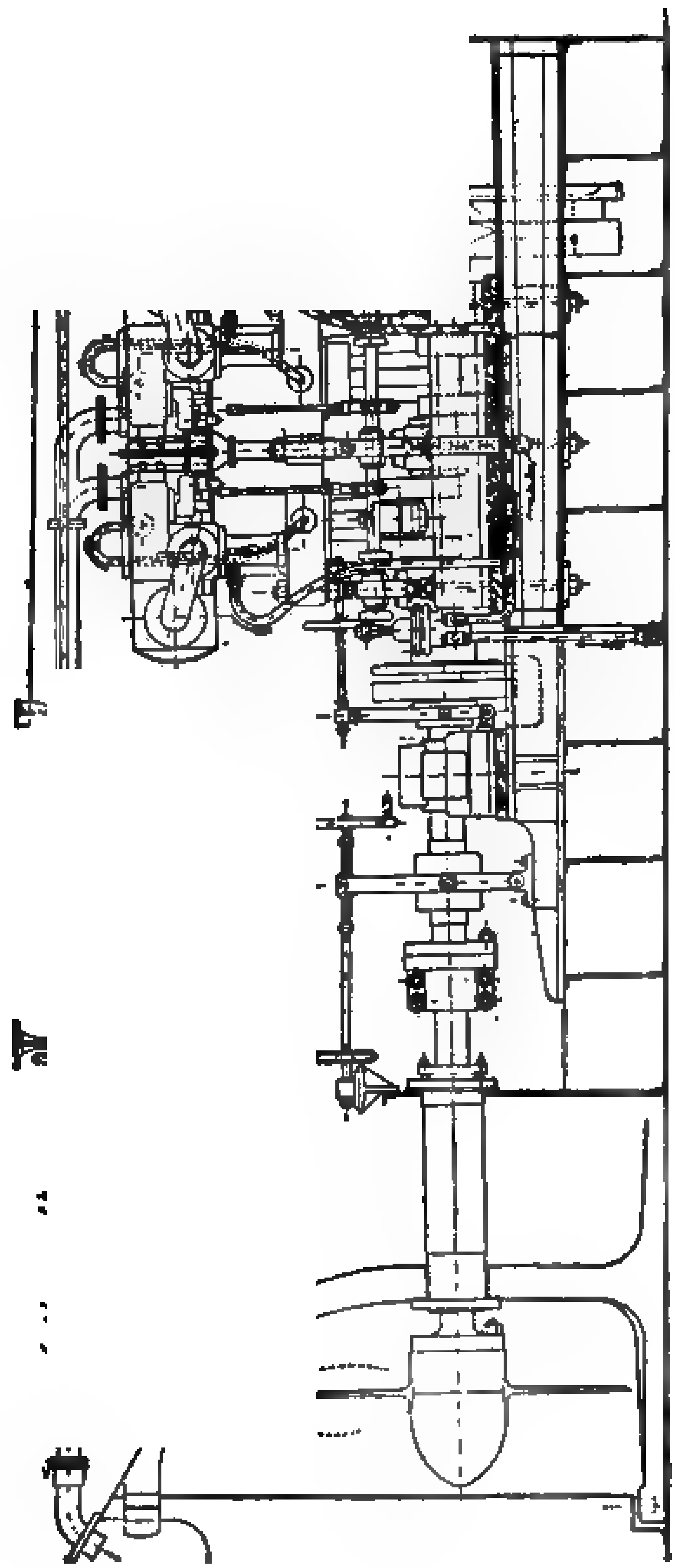


Fig. 142.—Sectional View of Simplex Boat Engine. About 1896.

in the oil receiver is maintained by a pump worked from the motor, which sends the oil to a smaller reservoir, also under pressure, connected to the cylinder. Another pump supplies water for the cooling jacket. The Capitaine launches are driven by ordinary petroleum, not benzine or inflammable spirit. The engines are made vertical only, in sizes from 1 to 8 B.H.P. single cylinder, and 10 B.H.P. double cylinder. By Grob & Co. they are constructed of the "Hammer Frame Type," two cylinder, up to 23 B.H.P. Hundreds are in use abroad, especially at Hamburg and on the Rhine.

The *Daimler* petroleum launch is, like the Capitaine, an application of the Daimler engine to propel a boat, with special apparatus to transmit the power to the screw. It has already been successfully applied for driving small boats, and has been fitted in about 600 launches; a 37 feet launch driven by a 10 H.P. Daimler oil motor was supplied to the London County Council. The author has inspected one of these little petroleum launches on the Thames. It ran quietly, with no smoke and little smell, was easily steered, the direction reversed, or the boat stopped at a moment's notice. The speed varied from 8 to 11 miles an hour. Many of the Daimler launches are at work in Germany, but they all have the disadvantage of using light petroleum of 0·68 or 0·70 density, and care must be taken in handling an inflammable substance of this nature. A vertical four-cylinder 10 H.P. Daimler boat engine was exhibited at Chicago. In its construction, vaporisation, and ignition of the oil, the engine does not differ from the type already described. The motor always works in the same direction, and is connected to the screw shaft by a disc and friction coupling. If all three are in connection the boat goes forward; by turning a handle two side friction discs are brought into play, and the motion reversed. Instead of this gear some boats carry propellers with reversible blades. When the engine is running at its normal speed of 480 revolutions per minute, the boat attains a speed of 15 miles an hour, and the consumption of oil is about 0·64 lb. per mile. The engine, oil tanks, and exhaust are arranged in the same way as in the Capitaine launches, and one man is sufficient to steer, and to drive the motor. Another boat about 40 feet long, driven by a Daimler engine with two diagonal cylinders, and pistons working on the same crank shaft, has been built by Treichler, of Zurich. These boat engines are made vertical only, with one, two, or four cylinders, in sizes from 1 to 10 H.P.; the boats run at a speed of 5½ to 9 miles an hour, and carry 6 to 30 passengers.

Messrs. *Vosper*, of Portsmouth, construct the Roots engine for river work, and make oil launches in sizes from ½ to 20 B.H.P., with one, two, or four cylinders. About 75 of these successful little launches have been already built, although

their manufacture is comparatively recent. One advantage of having several cylinders is that, by bringing one or more into use as desired, the power can be accurately adjusted; for intermittent work, as with barges going through locks, &c., this is a desirable arrangement. A 12 H.P. engine has lately been fitted on a barge, the boat itself carries 32 tons, and tows two boats of 30 tons burden each. An oil yacht, with four-cylinder Roots engine, has also been constructed by Messrs. Vosper, fitted with reversing propeller; the engine runs continuously, and the speed of the boat is regulated by turning on or off two or three of the cylinders, as required. Another launch was fitted with a 6 H.P. double-cylinder engine, and ran 2,000 miles without requiring attention. The larger engines run at 240 revolutions, with a piston speed of 360 feet per minute, the smallest at about 500 revolutions, with a piston speed of 630 feet per minute.

The *Griffin* oil engine has also been fitted to a petroleum launch. The method of transmission consists of two screw propellers, of right and left hand pitch, mounted loose and concentric to each other on a shaft through which passes a rod. By moving a handle one or other propeller can be connected to the motor shaft, by means of a double friction clutch. To stop the boat both propellers are disconnected. To reverse the motion the forward propeller is thrown out of gear, and the backward propeller connected to the screw shaft, the engine working always in the same direction.

The earliest application of oil engines to river work was by Messrs. *Priestman*, and they still make many of these vertical motors, in sizes from 2 to 65 B.H.P. Hitherto, in these and all other engines applied to boats, the vertical type only has been adopted. The Priestman have usually two or four cylinders, and are much used for barges and other purposes, where the safe working of the engine in unskilled hands is the first consideration. They are now employed on many rivers and inland seas of Europe. Transmission is effected by a reversible propeller, the movement of the boat being altered, while the engines run continuously in the same direction. The reversal of the propeller blades is obtained by a hand wheel near the steering gear, the direction of rotation of the screw shaft not being affected, as in other engines.

The special feature of the *Forest* engine is that the rotation of the engine itself is reversed, and not that of the screw shaft. These ingenious vertical motors carry a valve shaft, and double set of cams for reversing the motion, and are made in sizes fron 2 to 100 H.P. nom., running at 300 to 180 revolutions per minute. The oil used is of 0·70 density. Other engines which are capable of application to river purposes are the Trusty and Hornsby, but they have not hitherto been much used.

Portable Engines.—Oil motors for agricultural work have

of late years made much progress, and are beginning to compete with steam. This is not surprising when their advantages are considered. Gas engines are, of course, useless in the country, where the chief demand for this class of engine arises, because there are no mains or gas works at hand. Steam engines must have a boiler, and a provision of water and fuel. Portable oil motors are easily handled, compact, light, and require only two small tanks, one for oil, one to hold water for the cooling jackets; they are easily and quickly started and stopped, and oil may be procured anywhere. The chief drawback to their use is that they are rather delicate, sometimes apt to get out of order in unskilled hands, and do not bear well jolting over rough roads in moving them about. These and other defects, especially the smell, will doubtless be overcome before long. Although shown at various Exhibitions, these engines have scarcely emerged from the experimental stage, and much improvement may be expected as soon as they are more widely known and used. For portable engines petroleum is much to be preferred to lighter oils, because a certain quantity must be carried. Motors igniting the charge spontaneously, as it is called, without an external flame, have also a considerable advantage in open windy places over those carrying an exposed light, which often goes out.

Three important series of trials of portable and stationary oil engines, with special reference to agricultural work, were made in 1894, in Germany at Berlin by Professors Schöttler and Hartmann, in France at Meaux by M. Ringelmann, and in England at Cambridge. The reports of these trials give full particulars of the different engines submitted to the tests, and furnish the best accounts of the progress hitherto realised. In the Berlin trials twenty-seven engines, portable and stationary, of 2 to 12 H.P., were exhibited by fifteen different firms. All the most important German makers, with the exception of Adam and Benz, were represented, and one English firm, Robey. The engines were repeatedly and severely tested with American or Russian oil of 0·80 to 0·82 density. Not only was the consumption of oil per B.H.P. per hour determined at half, full, and maximum power, but other working details were investigated. The time required to get the engine into full work, the number of explosions missed, the extent to which the horse-power could be increased beyond normal full power, to meet unforeseen demands, supervision required from the attendants, steadiness of external flame, and cleaning after a prolonged run, were all noted. Particular attention was paid to the following important points:—The build of the engine, to avoid vibration with the wheels; shielding of the lamp from sudden extinction by wind; method of cooling the cylinder, quantity of cooling water, efficiency of the jacket, and finally the harmonious co-ordination

of all the parts to form a complete portable engine, and not, as was the case with several motors, only a stationary oil engine mounted on wheels. It was found that unless the jacket was in satisfactory working order, the cylinder either became too much cooled and the heat efficiency was reduced, or too little heat was carried off and the engine worked badly. The Altmann portable engine gave the lowest consumption per B.H.P. hour—0·73 lb. petroleum—and the best heat efficiency. The most economical stationary engine was the Swiderski-Capitaine, using 0·72 lb. oil per B.H.P. hour; the Grob and Deutz-Otto were also highly commended.

Eight portable engines took part in the Meaux trials—two English, three French, two German, and one Swiss motor. The same Russian oil of 0·82 density was used throughout, and the power was limited to 4 H.P. The Merlin gave the lowest consumption of oil,—0·70 lb. per B.H.P. hour,—and the Grob the highest heat efficiency. It was found that the general classification of the engines by the judges, with respect to their economy and excellence of construction, followed the heat efficiency, or the ratio of heat turned into work to total heat supplied. The experiments were on the same lines as those at Berlin, and the results in the original report are plotted in curves, and shown in diagrams. The quantity of air required for combustion was specially determined from the number of explosions, the volume of the piston, and the consumption of oil. When the actual volume of air was in excess of this theoretical quantity, the explosions were weak; when it fell below it, imperfect combustion was the result. Variations in the speed were also noted.

The trials of oil engines at Cambridge were in connection with the Royal Agricultural Society, and fifteen engines were entered for competition. These included some by all the best English makers except Messrs. Priestman, but no foreign motors were exhibited. In these trials, as at Berlin, the primary object was to determine how far oil engines could be relied on for farm work when handled by unskilled labourers, and simplicity of design, strength, durability, stability, and freedom from internal fouling, were specially tested. The engines were first run on the brake for three days of ten hours, then with full load, without any intermediate cleaning. None exhibited any traces of soot or dirt, though in all the oil was vaporised in a different way. Russian oil was used, of 0·82 specific gravity, and the power was fixed at from 4 to 16 B.H.P. The stationary engines with the lowest consumption of oil were the Hornsby, using 0·91 lb., and the Crossley-Otto, 0·90 lb. per B.H.P. hour. The consumption of the Premier, Trusty, and Campbell was about 1 lb. per B.H.P. hour. On the full-power trial the consumption in the Crossley-Otto was only 0·82 lb. oil per hour per B.H.P. The Hornsby and the Crossley were commended for economy, efficiency, and

steadiness. The portable engines exhibited by these firms were also the best, with the lowest consumption of oil per B.H.P. hour. Most of the engines exhibited were good, but the examiners, both English and foreign, in the three series of trials, were of opinion that in all there was room for improvement. For detailed results see Table of Tests.

Road Motor Carriages.—The latest development of oil engines, and one which has excited perhaps more public interest than any other, is their use to propel road carriages and bicycles. It must be confessed that at present, foreign motors hold the field, especially the Daimler. Probably, as soon as the law prohibiting the use of mechanical carriages on roads is repealed, English makers will adapt their engines, to a greater extent than they have yet done, to purposes of locomotion. In the opinion of the most competent observers, oil engines are destined to propel the mechanical vehicles of the future, the difficulties of utilising steam, electricity, or other forms of motive power being too great to promise a successful solution. Carriages propelled by compressed gas may possibly compete, and the Serpollet superheated steam and other steam engines are also in favour, but up to 1896 nothing has appeared to rival the popularity of the Daimler oil motor carriage.

In 1894 the proprietors of the *Petit Journal* at Paris held a competition of self-propelled road motor carriages from Paris to Rouen (79 miles). It was open to all kinds of vehicles worked by motive power, but those seating less than four persons were not eligible for the first prize. The chief conditions were security, easy management, and cheapness, and the speed was limited to 7½ miles an hour. So many carriages were at first entered that preliminary trial trips to select the best were found necessary, and this reduced the total number competing for the final run to 21. The list of entries, including some that failed to appear, may be divided into—23 petroleum carriages, of which 10 were Daimler; 12 steam; 2 driven by compressed air or gas; 1 by electricity; 1 by steam and petroleum. The first prize was divided between the two French firms of Panhard & Levassor, and Peugeot Frères, both makers of the Daimler carriage. The fourth was also awarded to an improved type of the Daimler, and the fifth to M. Roger; the others were given to steam carriages. The principle object of this trial was to determine the best motor carriage for ordinary use. In a second competition in 1895, between Paris and Bordeaux, special stress was laid upon the speed attained over a long distance. Twenty-eight vehicles were entered, and most of them ran from Paris to Bordeaux and back, a distance of 750 miles. The average speed was 15 to 16 miles an hour, and the carriages were examined immediately after the run, before any cleaning. The first two prizes were again awarded to the Daimler motor car. Petroleum

bicycles and tricycles were also tested, but these must be considered as at present in an experimental stage, and not as vehicles seriously competing with other means of locomotion.

Another exibition, chiefly American, was held in 1895 at Chicago, and amongst the competing motors was the new Kane-Pennington. A small exhibition of horseless carriages was held at Tunbridge Wells in 1895, where, with the exception of MM. de Dion and Bouton's petroleum tricycle (also shown, though not run, at Bordeaux), all the oil motor carriages were of the Daimler type. An important competition has been arranged for 1896 by the proprietors of the *Engineer*, when four prizes, amounting in the aggregate to £1,000, will be awarded. The first two of £350 and £250 will be given respectively to motor carriages holding four or more people, weight not to exceed 2 tons, and two or three people, weight not to exceed 1 ton. The other two prizes of £250 and £150 will be for goods carriages, conveying respectively 1 ton and 5 cwt. of parcels, the weight in each case not to be more than double that of the goods. The distance traversed will be 200 miles, no speed to count over 10 miles an hour. The carriages may be propelled by any mechanical means, but must be self-contained; the density of the oil used is fixed at 0·8, and flashing point 73° F. (Abel's test).

In all these trials the *Daimler* motor carriage has hitherto held the first place. It is made in France by MM. Panhard et Levassor, and Peugeot Frères; the former place the motor on the two front wheels of the carriage, MM. Peugeot under the back seat. The latter arrangement is usually preferred, as the exhaust gases and smell from the oil are more or less carried away to the rear. The engine has two cylinders inclined at an angle of about 15° to the crank shaft, and is similar in type to the petroleum motor already described. The gearing, as in boats, is by pulleys and friction coupling, connecting to a shaft which actuates the rear wheels of the carriage. The engine itself runs at a constant speed of 600 to 700 revolutions per minute, and is disconnected from the driving shaft during a short stoppage. In the latest carriages the engine cannot be started until the cooling water is put in circulation. This water is contained in a small tank under the front seat, and is kept in continual circulation through the framework of the carriage. The rim of the flywheel is hollow, and holds the water by centrifugal action. It is sucked thence by a nozzle with considerable force into the cylinder jackets, and is carried in its passage beneath the floor of the carriage, to act as a foot warmer in winter. The force with which the water is drawn into the nozzle is sufficient to keep it in constant circulation. There are two brakes, a hand and a foot, the former being required only in case of emergency. The driving shaft has a slide and wheels,

which work on three other wheels on a shaft above, commanding three different speeds, but in passing from one to the other the motor is necessarily uncoupled. The direction of the carriage is changed by a conical wheel on the upper shaft, acting on two loose wheels. Between them is a sleeve with teeth, which produces a forward or back motion, according to the wheel with which it engages. This transverse shaft carries a pinion, acting on the axles of the hinder wheels.

A different arrangement has been adopted in England by the Daimler Motor Syndicate, the present makers of the carriage in this country. Four speeds are available, and are obtained by means of two pulleys and belts on the motor shaft, driving other pulleys on the carriage shaft; the speed is varied according to the pulleys put in tension. A further change of speed is obtained by the action of spur wheels. The carriage can be driven up to 16 miles an hour, but from 8 to 10 miles is the average. It will ascend a gradient of 1 in 10, and sufficient oil can be carried for a distance of 200 miles; 4½ gallons is enough for a 60-mile run. To propel a carriage holding four people, a 3½ H.P. motor is required. From these details it will be seen that this carriage is a new and successful application of oil engines, but it can only be worked with light petroleum of 0·68 to 0·70 density, and this is not only highly inflammable, but it cannot at present be purchased in England. There is also a good deal of vibration, a defect which will doubtless be remedied in the future.

The *Roger* carriage is also used in some parts of France. The speed and action are the same as in the Daimler, the single cylinder engine is of the usual four-cycle type. In this carriage nothing is placed in front, the engine, oil, and water tanks being all beneath and behind the back seat. The engine is single acting, horizontal, and runs at 300 revolutions per minute, with electric ignition. The transmission gear is made by a shaft with loose and fixed pulleys and belts, all wheels being avoided, and the axle of the carriage is driven by a chain from an intermediate shaft. Connection is made or interrupted by means of two sets of levers. No governor is required, the speed being regulated by the driver of the carriage. It is varied by tightening or loosening the belts, or by checking the supply of oil to the carburator.

The *Tenting* carriage also took part in the Paris-Rouen competition, and covered the distance in 7 hours. It is worked by a two-cylinder horizontal 4 H.P. engine, running at 240 revolutions per minute, and the vibration is said to be less than with vertical motors. The speed can be varied by means of levers and friction coupling up to about 12 miles an hour. Light petroleum is used to drive the engine in both the Roger and Tenting carriages. A petroleum motor cycle has also been

brought out by Mr. Knight of Farnham, and the Crouan engine has been used in France to propel a carriage, but these motor cars are still in the experimental stage, and little can be done in England until the legal restrictions are removed. In M. Van Rennes' ingenious little petroleum cycle, the cylinder is cooled by an air instead of a water jacket.

Gas and oil motors are also used to drive fire engines and cranes. The Daimler fire pump has two cylinders. The pump shaft is set in motion by friction coupling from the flywheel of the motor, and carries two cranks set at an angle of 180°, actuating two pumps. It is geared to the motor shaft in the proportion of 1 to 6; the motor makes 480, and the pumps 80 revolutions per minute. The cooling water for the cylinder is sent on from the pumps. A crane is now working in Paris driven by a two-cylinder 16 I.H.P. gas engine, running at 140 revolutions per minute. The diameter of the cylinder is 9 inches, with 16 inches stroke, and the crane lifts 1 ton coal. Gas power is also used at the Liverpool docks for working cranes, pulleys, lifting weights and other purposes for which motive force is required, and it is estimated that 700 gas motors are at work in Liverpool alone. Mounted on wheels, oil engines, especially the Daimler, are used to generate a portable electric light, and a petroleum motor has lately been brought out for garden work. The author has also seen oil engines used in Switzerland for transporting railway carriages from one set of rails to another. These engines work to and fro, at right angles to the ordinary rails.

PART III.

AIR ENGINES.

CHAPTER XXVIII.

CONTENTS.—Theory—Cayley—Buckett—Stirling's First Engine—Stirling's Second Engine—Robinson—Later Type—Ericsson—Wenham—Bailey—Jahn—Rider—Jenkin's Regenerative Engine—Bénier—Genty—Diesel.

Theory.—In dealing with oil engines, no mention has been made of the theory of heat motors, and of their theoretical and actual heat efficiencies, &c., because in these respects oil and gas engines are based on the same principles. The effects of an explosion of coal gas with air, or oil vapour with air, when mixed in the cylinder of an engine, are similar, and the temperatures, from which the heat efficiencies are calculated, are the same. When we consider hot air engines, the conditions are different. There is no explosion, and no great rise or fall of temperature. A certain quantity of heat is applied to air, which expands and drives a piston, doing work. No boiler is needed, nor is any cost incurred for gas or oil from a tank, the air as working agent being taken from the surrounding atmosphere. There is no risk of explosion from inflammable gas or oil vapour. No change of physical state in the working agent takes place, and therefore all the heat generated and imparted to the air can, in theory, be utilised in work. The two main sources of waste of heat in gas engines are the cooling water jacket and the exhaust. In a hot-air motor there is no jacket (unless as a refrigerator), and therefore less heat should be dissipated, and more available for work. From these considerations, therefore, it seems as though a hot air engine must be not only better in theory, but more economical in practice, than other forms of heat motors.

Such, however, is not the case. Practically, hot air engines do not give results as satisfactory as might have been expected. Though the first engine of this type was designed in 1807, comparatively few have since been made, and their construction has not been much developed, except for special purposes. The reason for this neglect may probably be found in their low actual efficiency—that is, the amount of heat they turn into work. In theory the whole of the heat furnished to the air being utilised in expansion, a high ratio of efficiency should be obtained.

Practically expansion cannot be continued to the pressure of the atmosphere, and therefore some heat remains in the air, and is wasted at exhaust. The theoretical heat efficiency of an engine depends upon the range of temperature—that is, its highest and lowest working temperatures. But if heat be added to the air up to 900° F., and if the temperature of exhaust is 600° F., only the difference, or 300°, will be spent in expansion, and heat equivalent to 600° will be wasted. As in gas motors, the difficulty consists in utilising the expansive force of the agent, or air. Since expansion cannot be unlimited, only a certain proportion of the heat imparted can be turned to account as work. If it were possible by expansion to reduce the air in a hot air engine to the temperature it had before entering the cylinder, an efficiency of about 59 per cent. might, according to Professor Jenkin, be realised; the actual heat efficiency, or percentage of work to total heat received in these engines, is only from 7 to 10 per cent., not very different from that obtained in steam engines. The Stirling engine worked between the temperatures 343° C. and 65° C. The theoretical efficiency, according to the formula at p. 220, was $\frac{T_1 - T_0}{T_1}$, or $\frac{343° - 65°}{343° + 273° \text{(abs.)}} = \frac{278}{616 \text{(abs.)}} = 45$ per cent. The actual efficiency (see p. 406) was 7 per cent.

Difficulties of Hot air Engines.—To increase the efficiency and check the source of waste in these engines—that is, the high temperature of the exhaust,—the only method would appear to be to increase the ratio of expansion, and this can only be done by raising the initial compression of the air. But this does not produce any real advantage, because the pressure which is expended must be deducted from the pressure exerted upon the piston. To compress the air before it is admitted to the cylinder requires a certain amount of negative work, or work done *on* the working agent. The further compression is carried the greater the proportion of negative work, and the lower the proportion of positive work, or work done *by* the air. If the air be compressed to 100 lbs., 65 per cent. of the work would be required in theory to obtain this compression. It is also difficult to prevent leakages where high pressures of air are used. To keep all the parts of the engine perfectly air-tight is almost impossible, while to obtain an efficient working pressure it is necessary to use a large body of air. Air is a very bad conductor and does not absorb heat readily, and it expands in comparison with its bulk much more slowly than steam. In the Ericsson air engine, the pressure was only 3 lbs. per square inch.

Hot air engines are therefore bulky, and seldom suitable to replace steam or gas. Their special advantages are—1. Ease in working. 2. Absolute safety. For these reasons they are generally employed for driving fog signals on lightships, light-

houses, and in other isolated places, where these advantages outweigh the defects. They are also used for domestic and other purposes, namely, pumping, sawing, printing, driving tools, &c.

Cayley-Buckett.—The earliest hot air or caloric engine was introduced by Sir George Cayley in 1807, and patented by him in 1837. The original design has been adopted by Mr. Buckett, and practically the same engine is now made by the Caloric Engine Company. Fig. 143 gives a modified view of the Cayley-Buckett Caloric engine. It consists of two distinct parts, like the boiler and motor cylinder of a steam engine. A is the working

Fig. 142.—Buckett Hot Air Engine—Single Cylinder.

cylinder containing the piston P, B is the furnace in which the air is heated. Above the motor cylinder is a second pump cylinder J, into which air is admitted through the valve M, and compressed by the action of the piston P_1. The two pistons are connected to each other, and the up expansion stroke of the one forms the compression stroke of the other. The air, after being compressed in J, passes through the valve I and down the passage *d* in the direction of the arrows, till it reaches a cylindrical valve *c*, directly controlled by the governor G above it. Here the current of compressed air is divided. Part of it passes down the passage *g*, between the fire-brick lining W of the furnace and the outer casing, and is admitted through holes at the bottom of

the grate to the furnace B, where it stimulates combustion. The rest passes through the upper part of the valve, enters above the furnace at *f*, as shown by the arrows, and mingling with the products of combustion, prevents the escape of unburnt carbon. From here the hot air and products are carried off through the passage *h* into the motor cylinder, where by expansion they drive up the piston P. They are admitted through a lift valve V which, as well as the exhaust valve E on the opposite side of the cylinder, is driven by valve-rods, levers, and cams from the crank shaft K. Coal is fed into the furnace through the hopper H and the door D. During this time the valve R closes the top, to maintain the air pressure in the furnace during stoking. By opening the cock at *r* a portion of the hot air enters the hopper, and the pressure is equalised. As soon as D is closed, R is lowered into the furnace by the chain *s*. Combustion is regulated by passing more air, either under the furnace at *g*, or over it at *f*. If the speed is too great, the governor acts upon the cylindrical valve, and checks combustion by forcing the greater part of the air to mingle with the products of combustion from the fire. The Cayley-Buckett engine has no regenerator, but by an ingenious arrangement the cold air, after being compressed in J, is led round the valve V, admitting the hot air and gases to the motor cylinder. Thus the valve is kept cool, and the fresh charge of air heated on its way to the furnace. The air being exhausted at each stroke, a closed cycle cannot be obtained.

Trials.—In a trial on a 12 H.P. nom. double-cylinder vertical Buckett engine, the difficulties of this class of motor were well shown. The gross I.H.P. was 41·24 and the pump I.H.P. 21·04. Thus more than half the power was employed in negative work, leaving only 20·2 H.P. for working the engine. The B.H.P. was 14·39, and mechanical efficiency only 71 per cent. The mean pressure on the pistons was 18·5 lbs., on the pumps 16·78 lbs. per square inch. The coke consumption was 2·54 lbs. per B.H.P. per hour, and only about 8 per cent. of the total heat supplied was turned into work. The engine ran at 61 revolutions per minute, the diameter of the working cylinders was 24 inches, of the pumps 18 inches, stroke 16 inches. Fig. 144 gives an indicator diagram of the engine. A motor similar to the Cayley-Buckett was described with illustrations in *Engineering* in 1887.

Fig. 144.—Buckett Hot Air Engine—Indicator Diagram.

Stirling.—The first application of the principle of the regenerator to heat engines is due to Robert Stirling, a Scotch

minister, who, with his brother James Stirling, an engineer, took out several patents for heat motors, the first dating from 1827. Stirling's double merits as an inventor have not until lately received sufficient recognition from scientific men, perhaps because he was, like many other pioneers, in advance of his time. He first endeavoured to carry into practice the principle of a perfect heat engine (Carnot's cycle), and he also designed the regenerator. In a perfect heat motor the same quantity of heat is imparted to and withdrawn from the working agent, so that at the close of the cycle it returns to its original state, and the series of operations may be reversed. Robert Stirling obtained this perfect theoretical cycle by means of the second great improvement he introduced, the use of a regenerator, in which the heat of the working agent (air) is stored as it leaves the cylinder, and refunded afterwards, as it returns to the furnace. Many scientific men are of opinion that the proper development of the principle of the regenerator affords the chief possibility of improving the working cycle of heat motors. The regenerator has been ingeniously called a "filter," because both the hot and cold charge are "filtered," or passed through it at their highest and lowest temperatures. It is intended to diminish as far as possible the waste of heat at exhaust. It acts by arresting and storing the heat remaining in the working fluid after expansion, instead of allowing it to escape to the atmosphere, and gives back this heat to the next charge in its passage to the cylinder. The result is obtained in this case by making the hot gases pass through thin metal plates, wire gauze, or other heat absorbing substances, to which they give up their heat, and carrying the cold charge back through the same metal to receive heat from it.

Stirling's First Engine.—Stirling took out two patents for hot air engines working with a regenerator. In the first, dated 1827, he proposed to have a motor cylinder and piston, an air pump and two hot air vessels. The vertical motor cylinder and air pump were attached to a horizontal beam driving the crank; an eccentric and parallel motion worked the pistons of the air vessels through a balance beam. Each of these air vessels or cylinders contained a plunger piston composed of thin metal plates forming the regenerator. A furnace being lighted beneath the cylinders, air, compressed by the air pump into a receiver in the base, was admitted at the bottom to start the engine, and to supply the loss by leakage. By its expansion it drove up the motor piston, and in its passage through the plungers gave some of its heat to the regenerator. The cylinder covers of the air vessels were kept cold, and the air on reaching the top became immediately chilled. The hot air cylinders communicated, the one with the bottom, the other with the top of the motor piston. As the air decreased in temperature its pressure fell, and both the motor

piston and the piston of one of the air vessels descended. At the same time the air in the other cylinder being heated expanded, and by its pressure drove down the piston of the motor cylinder. Each time the cold air descended, it passed through the regenerator, and became heated afresh.

In Fig. 145 a modified view of this engine is shown. A is the motor cylinder and P the piston, B the air or displacer cylinder, and D a plunger piston working in it, F the space where the air is heated by the fire. The plunger or displacer D is filled with brick-dust, or other non-combustible material. The circular regenerator R is round D, and consists of metal plates about

Fig. 145.—First Stirling Engine. About 1830.

$\frac{1}{40}$ inch in thickness and $\frac{1}{50}$ inch apart. E is the refrigerator at the top of cylinder B, and is formed of coils of copper tubes through which cold water circulates; the hot air from the displacer cylinder acts on the motor piston. The cycle of the engine is as follows:—When the displacer piston is at the top of cylinder B, all the air is below it in F, heated by contact with the fire. As the air expands, its pressure is transmitted to the working cylinder, and it drives up the piston P. The displacer piston is now driven down, and forces the air below, through the regenerator, into the vessel and refrigerator at the top of

cylinder B. While the displacer is in its lowest position, the motor piston comes down. The air in B, which has already deposited the greater part of its heat in the regenerator, is further compressed, and passes around the refrigerator pipes E, where it is cooled, the heat from the furnace being shut out by the non-conducting material in D. By the energy of motion left in the flywheel, D is lifted, and beginning to rise forces down the cold air above it through the regenerator, where heat is added to it before it reaches the furnace. The motor piston P is driven up by its expansion, and the cycle recommences.

Stirling's Second Engine.—In Stirling's second engine, introduced in 1840, Patent No. 8652, the regenerator and refrigerator are placed on one side of the cylinder. Fig. 146 shows the arrangement, the parts are lettered as before. C is the displacer cylinder, D the plunger, F the space below it, A the passage leading to the motor cylinder. E is the refrigerator cooled by water, I the passage to the regenerator. The action of the engine is the same as before. There are one motor and two hot air cylinders. The air is delivered into the cylinder by a small pump at a pressure of 150 lbs. per square inch, and passes through the regenerators from one hot air cylinder to the other, driving the motor piston up and down in its passage. There is no exhaust, the same air being used continuously, and a closed cycle is thus obtained. This engine presents in a compact form the main principles of Stirling's invention, and illustrates better than any other type of motor the construction of a perfect heat engine. Here we have the source of heat (the furnace), the source of cooling (the refrigerator), and between

Fig. 146.—Second Stirling Engine. 1840.

the two the regenerator, which abstracts heat as the air passes to the refrigerator, and refunds it as it returns to the source of heat. One of Carnot's chief propositions is here put in practice. Heat is imparted to the working agent at its highest temperature, and withdrawn at its lowest. In both cases its temperature, previous to this addition and subtraction of heat, is raised and lowered by the regenerator. A perfect reversible heat engine was the result, but in practice it did not work well, and only about 7 per cent. of the total heat produced was utilised as motive power. A Stirling engine was used to drive machinery for three years at the Dundee Foundry. It indicated 40 H.P., had a cylinder diameter of 16 inches, and 4 feet stroke, and required about 2½ lbs. coal per H.P. per hour.

Robinson.—A small engine embodying Stirling's principles was brought out by Robinson, and made by Messrs. Pearce & Co. of Manchester. It is very compact, with one vertical single-acting cylinder containing two pistons. The lower is the displacer and regenerator, and is filled with wire gauze, acting in the same way as in the Stirling engine. The section of the cylinder in which the displacer moves to and fro is lined with fire-brick, to retain the heat. In the upper part of the same cylinder is the working piston, and here the cylinder is surrounded by a water jacket, to serve as a refrigerator. The two pistons work through connecting-rods on two different cranks at right angles to each other; the crank of the displacer is in advance of the motor crank, and the displacer-rod works through a stuffing box in the motor piston. Instead of a grate and coal, in which much heat is dissipated, the temperature of the working agent is raised by a Bunsen burner, fed with air heated by passing through a jacket outside the chimney carrying off the products of combustion. When the displacer piston is at the top of its stroke, all the air below it is heated by the burner, expands, and drives up the motor piston. As the displacer comes down, it forces the air to pass through the regenerator into the space above, between the two pistons. Some of its heat has already been carried off by the regenerator, and it is here further cooled by contact with the cold water jacket of the refrigerator. The pressure falls, and the working piston descends. The displacer now rises, and the cold air is forced down through the regenerator. In its passage it regains the heat it had parted with, before it reaches the hot plate above the Bunsen burner, where it is heated afresh, and the cycle repeated. In this engine the only cost is the supply of gas to the burner, which is about ½d. an hour for a 1-man power engine. The air pressure is low, and no pump is used to supply loss by leakage; the power produced is very small for the size of the engine. The largest size made is a 2-man power, running at 270 revolutions per minute; the cylinder diameter is 8 inches, length of stroke

5 inches. A drawing of this engine is given in Professor Jenkin's valuable paper on "Gas and Caloric Engines" (*Proceedings of the Institution of Civil Engineers*, 1883), from which many details of this and other hot air engines have been taken.

A new type of this engine has lately been introduced by Messrs. Norris & Henty, of Manchester, and is shown at Fig. 147. The principle of the motor is the same, but the position of the two pistons is different, the working cylinder being horizontal, the displacer vertical, and the axes of the two in the same plane. B is the motor cylinder with piston, the displacer A has a hollow perforated piston I filled with wire gauze. C is the furnace in which any fuel can be used, but coke is preferable; for very small powers a gas flame, as in the earlier engine, is most convenient. There is no exhaust chimney, the air at D being used over and over again. The motor piston works

Fig 147.—Robinson Air Engine—Norris & Henty. 1895.

through the connecting rod H and crank pin G on to the crank shaft E, while two links on the same pin give motion to a lever F, which works the displacer piston. In other respects the action of the engine and the heating and cooling of the air are the same as in the earlier type. The displacer or regenerator is one-fourth in advance of the motor piston. The hollow bed plate to which the working cylinder is bolted may be filled with water, and then acts as a refrigerator. There is said to be no loss of air by leakage, because it is so rapidly cooled by the cold surrounding walls that the pressure falls below atmosphere when the piston in B is two-thirds out, and if any air escaped during the out stroke, it would be drawn in again by the vacuum during the return stroke. For the same reason no pump is required to maintain the supply of air. An engine of $\frac{3}{8}$ H.P. is said to work at a cost of 1d. per hour per H.P. The motor is made in sizes from 750 feet lbs. per minute to $\frac{3}{8}$ H.P., and runs at 300 to 150 revolutions per minute.

One chief reason for the low pressures and small amount of work obtained from the Stirling, and its failure as a practical engine, was that the air was not brought into direct contact with the heat of the furnace. In the displacer cylinder, a thin metal plate intervened between the fire and the hot air, the bottom of which was soon burnt by the great heat. There is no exhaust in engines of this type, the air being used over and over again, and the pump only replacing loss by leakage, but this advantage is counterbalanced by the difficulty of heating the air. In the Cayley-Buckett engine it is passed through the furnace and, mingled with the products of combustion, drives up the motor piston, and is exhausted after expansion, as in an ordinary heat engine.

Ericsson.—The latter type of motor is best exemplified in the celebrated engine produced by Ericsson in 1826. As an engineer, Ericsson was a genius not inferior to Robert Stirling. During the first half of this century he introduced numerous mechanical inventions, and is said to have designed the first screw propeller. In his engine hot air was used in conjunction with steam. It was drawn into a furnace below a steam boiler, and after producing combustion of the fuel, and evaporating the water, it was carried off, together with the products of combustion, and drove up the piston of an air cylinder by its expansion. On its way it passed through a regenerator. In an alternative engine described in the same patent, it was proposed to mix the products of combustion and the hot air with the steam, and admit them alternately at either end of the motor cylinder, as in an ordinary double-acting engine. After expansion, they were exhausted into the atmosphere. Thus the heat was applied directly to the air. Of course it was impossible to use the air over again, since it was required fresh at every stroke, to support combustion.

These two engines, the Stirling and the Ericsson, form two distinct classes, into one or the other of which all hot air engines can be divided. In the first, the air does not come in contact with the flame, but is heated by conduction and by the regenerator, and is not discharged at each stroke. In the second, it is applied directly to feed the flame, and, mingled with the products of combustion, produces motive power by expansion, after which it is exhausted. In both engines the practical heat efficiency, as compared with the theoretical, is very low. Admirable as types, they cannot, for the amount of heat they turn into work, be ranked with gas, oil, or steam engines. The chief reasons for this deficient utilisation of heat have been already explained. A large quantity of heat must be added to the air, before its temperature is high enough to produce a proper working pressure. This necessitates large cylinders, that a sufficient volume of air may be heated, and their bulk, weight, and friction are serious drawbacks to the extended use of heat motors of this type. In a Stirling 37 H.P. engine, the maximum temperature was only 650° F., and the weight 1 ton per I.H.P. The consumption of coal per effective H.P. is also very great, especially in engines of the Ericsson type. The 600 H.P. engine originally made by Ericsson was said to consume 6½ lbs. coal per H.P. per hour, the heating surface of the regenerator was 4,900 square feet. Another of ¾ H.P. was used for thirty years by the Trinity House authorities on board a lightship, and for driving a fog signal was found to give good results. In the Ericsson engine tested by Professor Norton, the I.H.P. was 321, and consumption of anthracite 1·8 lb. per I.H.P. per hour, but there were four motor cylinders, each nearly 14 feet in diameter. These two air motors form the standard types, followed more or less closely by all other hot air engines.

Wenham.—The Wenham engine, introduced about 1873, is in some respects similar to the Buckett. The motor is of the Ericsson type, and the air is heated by forcing it through a furnace lined with fire-brick, after which it passes to the vertical water-jacketed motor cylinder, driving up the piston by expansion. The distinctive feature of the engine is that the upper surface of the motor piston is used as an air pump. Air is admitted into the top of the cylinder through an automatic lift valve, when the piston is in its lowest position, and the pressure has consequently fallen. As the piston rises, forced up by the expansion of the heated air from below, the pressure closes the valve, and as soon as the air is compressed to 15 lbs., it forces open another lift valve, and passes to the furnace at the side. In the passage through which it is led off is a valve, connected to the centrifugal governor. Here the current of compressed air is separated, part passing over and part beneath the fire grate, to stimulate combustion.

The governor regulates the proportions of the two, and thus the rate of combustion, and the pressure of the air delivered to the motor cylinder. Ordinary coal is burnt as fuel. The hot air, after passing upwards, is led off, mingled with the products of combustion, and admitted to the bottom of the motor cylinder through a lift valve, worked by a cam on the main shaft. A similar cam operates a second lift valve for the exhaust. The admission and discharge ports are both at the bottom of the cylinder. The engine is single-acting, the expansion of the hot air drives up the piston, it descends by the motion of the fly-wheel and by the pressure of the air stored above it, and drives out the burnt products. There are two piston-rods, both working on to the same crank shaft. The consumption is said to be as much as 8 lbs. of coal per H.P. per hour, which is probably the reason why these engines have not hitherto been much used. A description with drawings will be found in *Proc. Inst. Mech. Engs.*, 1873.

Bailey.—The Bailey engine, shown at Fig. 148, is constructed on the Stirling principle. The products of combustion pass from the furnace to the displacer and power cylinder, where they mingle with and heat the air, driving the piston. The cylinder is horizontal, but in most respects, and especially in the arrangement of the regenerator, the Bailey resembles the vertical Robinson engine. There is one long cylinder, A_1, the crank end of which, closed by the piston, is surrounded by a water jacket, and acts as a refrigerator. The other end serves as the heater and regenerator. This cylinder contains two pistons—P the motor, working on to the crank by a connecting-rod, *c*, and series of levers, and P_1 the long displacer, the connecting-rod of which

Fig. 148.—Bailey Hot Air Engine.

passes through the motor piston, and works on to a separate crank at right angles to the main crank. The displacer P_1 does not fit closely into the cylinder A_1, but a small passage is left between them, shown at D. This piston is used merely to cause

the air to travel backwards and forwards in the cylinder; all the work, including that of driving the displacer, is done by the motor piston. At H is a steel casing enclosing the inner end of the cylinder; F is the furnace. The hot gases and products of combustion pass upwards from the furnace over the fire bridge, in the direction of the arrows, into the space G round H, and the burnt products are carried off through the flue C. The air enclosed in the space L becomes highly heated, and drives out the displacer. As it reaches the narrow opening D, it is chilled by the water jacket, and before it has passed into L_1 on the other side of the displacer piston P_1, it has parted with all its heat. As the air cools its pressure is reduced, the working piston and displacer make their return stroke, and the cold air is drawn back into the space L, to be reheated first by the steel casing, then by the furnace gases. Thus the heat is added when the temperature of the air has already been raised by the hot end of the cylinder, and withdrawn by the refrigerator after it has been cooled by expansion.

The Bailey engine is said to be based on the designs of MM. Lehmann & Laubereau, but it is really an English engine, strictly modelled on the Stirling type, though the idea of a regenerator is not much developed. There is no exhaust for the hot air, which is used continuously, and the loss by leakage is replaced from time to time through a small valve, when the pressure falls below atmosphere. The absence of valves is an advantage in this class of engine, because the great heat necessary to obtain a working pressure soon wears them out, and causes them to become loose. As the air is introduced direct from the surrounding atmosphere, and no compression pump is used, the maximum pressures are very low. The following details of a trial from Professor Jenkin's paper on "Gas and Caloric Engines" gives the working of a Bailey hot air engine:—The speed was 106 revolutions per minute, and the engine indicated 2·37 H.P.; the mechanical efficiency was 55 per cent., the brake H.P. being 1·31. The stroke was $6\frac{7}{8}$ inches, diameter of cylinder $14\frac{5}{8}$ inches. The highest pressure obtained was 14·7 lbs. per square inch above atmosphere, and the temperature at this pressure was 823° C. The consumption of coal was said to be under 10 lbs. per hour. Fig. 149 gives an indicator diagram taken during this trial. The engine works easily and steadily, and requires scarcely any attendance. Messrs. Bailey make 7 sizes, from $\frac{1}{4}$ to $3\frac{1}{2}$ H.P., at speeds from 120 to 80 revolutions per minute.

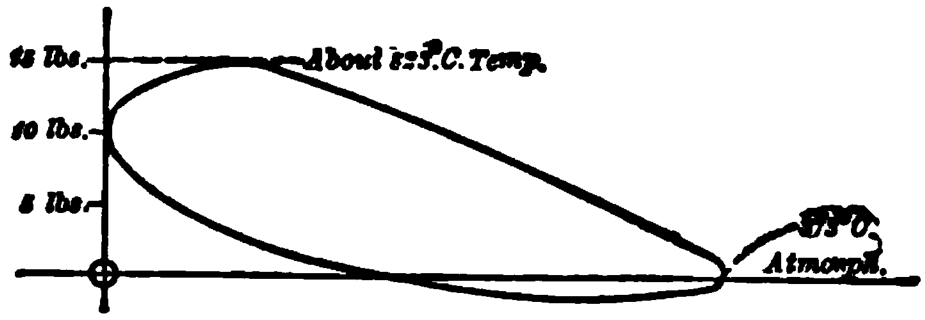


Fig. 149.—Bailey Hot Air Engine—Indicator Diagram.

The figures of the trial show that to obtain a pressure of only one atmosphere, a relatively high consumption of coal and high temperature are necessary. These are partly owing to the transmission of the heat through metal to the air. But the difficulty is not removed by passing the air directly over the fire, as in the Ericsson engine, and driving the piston by the expansion of the hot furnace gases. Since the air must be discharged at every stroke, fresh air is continually introduced, and much of the heat obtained is wasted at exhaust. It has also been found that the air, in its passage through the furnace becomes charged with grit and unburnt carbon, which score the valves and passages, and cause friction and wear of the working parts.

Jahn.—A vertical engine on a similar principle (Hoffmann's system) is made by Jahn & Co., Boitsfort, Belgium, and was exhibited at Antwerp in 1894. This motor has also two pistons, a displacer below and a motor above, working vertically in the same cylinder. The latter is divided into three parts by layers of isolating material, and the heat from the lower part, where the air is heated by a furnace, cannot pass into the upper, which is kept cool by a water jacket. The rod of the displacer piston passes through the centre of the hollow motor piston rod, and both work on to the same crank. The air heated by the furnace below the displacer passes upwards, and drives up the motor piston; when cooled by the water jacket, it is again forced down by the displacer to be heated afresh by the furnace, and the cycle recommences. The crank shaft carries a governor which, if the normal speed is exceeded, allows part of the hot air to escape, or prevents fresh air passing to the furnace. The water in the jacket is circulated by a pump. As in the Bailey engine, the displacer merely causes the air to travel in one or the other direction, in accordance with the motion of the working piston. Drawings and a description will be found in *Zeitschrift des Vereines deutscher Ingénieure*, June 29, 1895.

Rider.—The Rider is an ingenious little hot air engine brought out in America, and made in this country by Messrs. Hayward & Tyler. It is a compact and handy single-acting motor, and is used for domestic purposes, and to pump water. It presents almost all the features of the Stirling type, the regenerator, the furnace below heating the air through metallic walls, with no exhaust or other valves. There are two vertical cylinders, as shown at Fig. 150; one is heated by the furnace beneath, the other is kept cool by a water jacket. The same air is used continuously, and is passed alternately from one cylinder to the other. Unlike the Stirling, however, the motor piston is placed in the hot cylinder of this engine, and it is here that the power is developed. A is the working, and B the second cylinder, which acts as compressor, displacer, and refrigerator. Each has a plunger piston of unequal stroke and diameter, P and P_1, working

through connecting-rods, J and J_1, on two cranks on the main shaft, carrying the flywheel. The cranks are set nearly at right angles. The cylinders are open at the top, closed only by the pistons. W is the water jacket surrounding the compression cylinder B; the piston of cylinder A ends in a concave cylindrical

Fig. 150.—Rider Hot Air Engine.

part, F, over the furnace, round which the hot air circulates. Between the cylinders is a passage containing the regenerator R, formed of a number of very thin iron plates. As the air passes through this regenerator it either takes in or gives out heat, accord-

ing to the direction in which it is going, whether from the hot to the cold cylinder, or back again. The fire at G greatly heats the air in the space above it at F, and forces up the piston P by expansion. Meanwhile the displacer P_1 is at the bottom of its stroke, it then begins to rise slowly, drawing over into cylinder B, by its suction, part of the hot air in A. Until this air is completely cooled, its pressure helps the ascent of piston P_1. When the motor piston P has reached the top of its stroke, the other plunger is more than half way through, and as P descends, it displaces all the hot air in cylinder A, and drives it into the cold cylinder B, through the passage and regenerator R, where a large portion of its heat is deposited. The air, already reduced in temperature, is further cooled by the water jacket W, its pressure falls, and the plunger piston P_1 descends, compressing the cold air below it. It is during this period—the last part of the down stroke of P_1—that the flywheel does work, there being no air in the hot cylinder to act by expansion, but the power exerted during this compression stroke is not nearly as great as the power previously developed by the expansion stroke in A. By the time the plunger P_1 has reached the end of its stroke, the motor piston has begun to rise, and the air is again displaced and transferred from the cold to the hot cylinder. As it passes back, it absorbs heat from the regenerator, and more heat from the concave part F in the motor piston, which forces it against the hot walls of A. When it reaches the furnace the cycle recommences.

The chief peculiarity of the Rider engine is that the motive power is not only generated but exerted in the hot cylinder, above the furnace. This is not a desirable arrangement. In all his various designs, Stirling was careful to keep the motor cylinder cool, and even in the modifications of his engine where all the operations take place in one cylinder, that part of it containing the working piston is cooled by a water jacket. The Rider engine is mostly made in sizes from 1 H.P. and less. The speed is from 100 to 140 revolutions per minute, and the maximum pressure about 20 lbs. above atmosphere. The consumption of coke varies in $\frac{1}{4}$ and $\frac{1}{2}$ H.P. engines from 25 lbs. to 18 lbs. per B.H.P. per hour.

Jenkin's Regenerative Engine.—A hot air engine on the Stirling principle, with a regenerator, but in which hot air passes directly over the furnace and, mingled with the products of combustion, drives up the piston, was introduced by Fleeming Jenkin. In the first type of his Fuel Regenerative engine, patented in 1874, coal gas and hot air were used together to form an explosive charge. This vertical engine had a combustion cylinder with displacer piston, a motor cylinder with working piston, and two pumps for compressing the air and gas, all driven from the same crank shaft. The combustion cylinder is lined with fire-brick, and has below it a chamber formed by the clearance space, and continually maintained at a white heat by the

explosions of compressed gas and hot air taking place in it. The displacer piston contains the regenerator of fine wire gauze, as in the Stirling engine; at the top of this cylinder is the cooling chamber. The air from the air pump is driven into the upper part, and forced downwards through the regenerator by the displacer piston as it rises. In the combustion chamber it mingles with the coal gas or petroleum admitted into the cylinder by a second pump, and the compressed air, already heated by its passage through the regenerator, produces the ignition of the charge. The hot gases and products of combustion expand, and, entering the bottom of the motor cylinder at a high pressure, force up the piston. The exhaust gases are passed through the regenerator before being allowed to escape into the atmosphere. A drawing of this engine will be found in Robinson.

A second regenerator engine, designed by Professor Jenkin and Mr. Jameson was described, with drawings, in Professor Jenkin's paper already referred to. Here the object was to construct an engine of the Stirling type, but in which the heat was directly transmitted to the motor piston. One cylinder only was used, the upper part containing the refrigerator, and the lower the regenerator. To keep in the heat, it was found necessary to line, not only the clearance space, but the cylinder itself outside the regenerator with non-conducting refractory material. Great difficulty was experienced in dealing with this substance, owing to its porosity. The inventors were finally obliged to use a fire-brick lining of great thickness, and a separator or metal plate, dividing it into two parts. Even with these precautions the clearance space was much too large, and there was consequently great loss of pressure. To work the engine a coke fire was made below the cylinder, and the air as it became heated drove up the pump or displacer. As it expanded, it passed through the regenerator round the circumference of the cylinder. Here heat was withdrawn from it, and it became still further cooled by contact with the refrigerator or water jacket, at the top of the cylinder. The contraction of the cold air caused it to pass downwards again to the fire, and heat was restored from the regenerator, and from the fire-brick lining of the clearance space. This engine did not go beyond the experimental stage.

Bénier.—MM. Bénier, whose gas engine is mentioned at p. 162, brought out in 1866 a hot air motor, which appears to have met with considerable success. It is a vertical single-acting engine; the piston-rod works through a horizontal beam on to the connecting-rod and crank. Fig. 151 gives an external view. There is one motor piston, with furnace below; the connecting-rod and crank shaft are shown to the left in the drawing. Another rod works the horizontal air pump, seen through the opening in the base of the engine, by means of a rocking lever. The air pump is single-acting, and sends a current of air at each

stroke to the furnace below the cylinder through a slide valve. The valve works between a slide face and cover, and has openings corresponding to ports in the cylinder. It is driven by a cam on the crank shaft actuating a lever, and is held in position by springs. The centrifugal governor inside the central column is worked by a pulley on the crank shaft. It acts through a small lever, a series of rods, and a disc, upon a small crank below the air pump, and closes the air opening from

Fig. 151.—Bénier Hot Air Engine. 1886.

the pump to the furnace more or less according to the speed. A spring maintains the disc and crank in position. The air is drawn cold into the air pump, and delivered at a pressure of 15 lbs. per square inch into the furnace, where it expands and acts directly upon the piston, as in engines of the Ericsson type. The greater part passes downwards to the grate, but part is ingeniously introduced into a small groove hollowed out in the cylinder. The motor piston is very long, and the lower part is made slightly smaller than the cylinder, and does not exactly fit it. In the space thus formed round the lower end of the working piston, the current of cold air circulates, keeps the piston cool, and prevents the escape of dust or unburnt carbon from the furnace below. The exhaust is on the other side of the cylinder. The products of combustion are discharged through an ordinary lift valve, raised as the motor piston begins to descend, by levers acted on by a cam on the crank shaft. The furnace is fed automatically by means of two hoppers. The proper quantity of small coke for each charge is conveyed from

one to the other, and the second hopper, shown to the right in the drawing, discharges its contents into a port in a slide valve which, in its onward motion, shoots the coke down into the furnace. This distributing slide valve is driven by wheels from the crank shaft, and holds the grate hermetically sealed during expansion and the ascent of the piston.

The Bénier appears to be one of the simplest and most efficient of hot air motors, and requires no attention beyond cleaning out the grate once a day. For coast fog signals it has been tested and approved by the Trinity House Authorities, and is much used in France. Although it works without a regenerator, it gives fairly economical results. A 7 H.P. engine was shown at the Paris Exhibition of 1889, in which the consumption of coke was about 2 lbs. per H.P. per hour. In a 6 H.P. engine the average consumption, with varying loads, was 3 lbs. coke per H.P. per hour. A complete and careful test on a 4 H.P. nominal engine was made by Professor Slaby at Cologne in December, 1887. The speed of the engine was 117 revolutions per minute. The total indicated work in the motor cylinder was 9·23 H.P., pump 3·38 H.P.; available power only 5·85 H.P. The B.H.P. was 4·03, and mechanical efficiency 69 per cent. The consumption of coke was 3·6 lbs. per B.H.P. and 3·1 lbs. per I.H.P. per hour. All the items of heat expenditure were carefully noted, and it was found that only 6 per cent. of the total heat supplied was transformed into useful work. The makers give the consumption of coke at from 3·3 lbs. to 3·9 lbs. per H.P. per hour. The engine is made by the "Société Française des Moteurs à Air Chaud," in sizes of 4, 6, 9, 12, and 15 H.P. Some of these hot air engines are working in England.

Genty.—An air engine of a similar type to the Bénier has been brought out by M. Genty, and is made by the "Société des Moteurs aérothermiques." A 17 B.H.P. motor was bought by the French Government to drive the dynamos generating the electric light on the Cap d'Antifer Lighthouse, and to compress air for a syren. The engine has a vertical motor cylinder on one side, and an air pump on the other side, of a horizontal beam, supported in the centre by a column. The hollow foundation below serves as an air reservoir and regenerator. The valves admitting air to the pump have no springs, but are held closed by a number of small balls, which are said to act quickly and effectually. On leaving the pump the air is forced through the regenerator, a series of tubes round which the exhaust gases circulate, and it is thus heated to a temperature of about 1,260° F. From thence it passes to the motor cylinder through a throttle valve acted on by one of two governors, the other governor regulates the pressure in the air reservoir and the intensity of combustion, according to the power required. The furnace is at

the bottom of the motor cylinder, and the hot gases from it expand directly beneath the piston, and drive it up. The cylinder is in two parts, the upper being cooled by a water jacket, and the lower perforated to allow free passage to the air. The hollow plunger piston is in three divisions, the lowest fitting into the grate, the centre carrying the piston-rod, and the upper having also a water jacket. The exhaust valve is driven by an eccentric from the crank shaft, and through it the gases pass to the air reservoir. The consumption of this engine is said to be about 2 lbs. coke per B.H.P. hour.

Diesel.—A new motor has lately been patented in Germany, England, and other countries, by Herr Diesel, of Berlin. It is still in the experimental stage, but the inventor hopes to obtain a very much greater economy of heat than has hitherto been reached. It is a single cylinder, vertical, single-acting engine, without a water jacket, employing the Beau de Rochas four-cycle, and designed to run at a speed of 300 revolutions per minute. The principle of the engine is as follows:—Air is compressed in the motor cylinder by the up stroke of the piston to a pressure of from 90 to 200 atmospheres, equal to about 800° to 1000° C. Into this highly compressed and heated air a small quantity of finely-powdered coal, gas, or oil is introduced at the dead point; spontaneous ignition of the inflammable mixture immediately takes place, and the piston is driven down. The inventor claims to utilise about 35 per cent. of the actual heat supplied in useful work, and experiments are now being made with a medium sized motor in Germany. A full description of the new theory of combustion on which the engine is based, will be found in Herr Diesel's new work, *Theorie und Konstruktion eines Rationellen Wärmemotors*. Julius Springer. Berlin, 1893. An English translation of this work, *Rational Heat Motor*, has lately been published by Messrs. E. & F. Spon, London.

APPENDIX.

SECTION A.

NOTE ON THE OIL INDUSTRY IN THE CASPIAN REGION.

(*From Marvin's "Region of Eternal Fire."*)

UNTIL 1872 the oil industry at Baku was a monopoly of the Crown of Russia, farmed out to a merchant named Meerzoeff. The European market was flooded with American oil, which was exclusively used, even in Russia, and it was to encourage the home trade that the Russian Government were induced to put an end to the monopoly. At that time there were 417 wells, with an annual output of 24,800 tons of oil, and the price of petroleum was £3, 10s. per ton. An excise duty was imposed until 1877, since which date there has been no tax or check upon the development of the petroleum industry. The first oil fountain was "struck" in 1873, and the abundant and continually increasing supply has reduced the price from forty-five kopecks to five kopecks per pood. The number of drilled wells increased from 1 in 1871 to 400 in 1883, and the production of refined oil from 16,400 tons in 1872 to 206,000 tons in 1883. The price of land in the oil district round Baku has also risen enormously, and in 1884 it varied from 10s. to £2 per square sajene = 7 feet square. The specific gravity of the crude oil is about 0·822; it yields 27 per cent. of kerosene or ordinary lighting oil, having a flashing point of 36° C.

Robert Nobel, a Swedish engineer, started his first oil refinery at Baku in 1875, and was soon joined by his brother Ludwig, who assumed the principal direction of affairs. The Nobels were the first to lay down a pipe line, at a cost of £10,000, instead of conveying the oil in carts to the distilleries, and the outlay was covered in the first year. There are now seven pipe lines, two belonging to Nobel Brothers, three to private Russian firms, and two to companies; 161 million gallons of oil are thus conveyed yearly to the refineries. Being foreigners, the Nobels had from the first to struggle with severe competition from the Russian firms, and after laying down their pipe line were next obliged to build their own steamers to receive the oil. The first oil or "cistern steamer" was constructed in the Nobel shipbuilding yard at St. Petersburg, and appeared on the Caspian in 1879. The firm have now a regular fleet of vessels, each holding about 750 tons of kerosene, as well as twelve smaller distributing ships on the Volga. They have also established a system of tank cars on all the Russian railways, and possess twenty-seven oil depôts at various chief towns in Russia. More than fifty-four million gallons are sold by them yearly, and they have over forty wells, one of which yielded, in 1882, 112,000 gallons of crude oil. The following table shows the output and price of petroleum from 1873 (the year after the monopoly was taken off) to 1883, and the production and total exports from 1884 to 1894:—

Year.	Output.	Price per Ton at Baku.
	Tons.	s. d.
1873 (monopoly abolished), . .	64,000	7 9
1874, ...	78,000	6 3
1875, ...	94,000	15 6
1876, ...	194,000	7 9
1877 (excise duty taken off), . .	242,000	12 6
1878, Nobel Period, .	320,000	8 8
1879, Nobel Period, .	370,000	6 3
1880, Nobel Period, .	420,000	3 8
1881, Nobel Period, .	490,000	2 6
1882, Nobel Period, .	680,000	2 6
1883, Nobel Period, .	800,000	2/6 to 6d. & lower.

Year.	Total Production of Crude Oil.	Total Exports of all Petroleum Products.
	Tons.	Tons.
1884, Nobel Period, .	1,451,600	850,000
1885, Nobel Period, .	1,871,000	1,056,450
1886, Nobel Period, .	2,580,600	1,175,800
1887, Nobel Period, .	2,661,300	1,416,130
1888, Nobel Period, .	3,100,000	1,800,000
1889, Nobel Period, .	3,306,450	2,470,000
1890, Nobel Period, .	3,854,840	2,725,800
1891, Nobel Period, .	4,661,300	2,943,550
1892, Nobel Period, .	4,806,450	3,243,550
1893, Nobel Period, .	5,435,480	4,000,000
1894, Nobel Period, .	4,903,220	4,651,600

From Redwood.

SECTION B

PROFESSOR CAPPER'S GAS ENGINE TEST.

December, 1892.

The author has been kindly permitted to publish the following experiment made on a 7 H. P. nom. Crossley-Otto engine, at which he was present.

The trial was carried out at the King's College Engineering Laboratory by Professor Capper. Annexed is his report:—

A series of trials has lately been carried out in my laboratory with a 7 N.H.P. Otto gas engine, constructed on the Beau de Rochas cycle by Messrs. Crossley Brothers, and in one which I made on the 7th December, 1892, interesting particulars were obtained as to the composition of exhaust gases, and the transmission of heat through the cylinder walls.

The engine was built in December, 1891, and completely fitted up for experimental purposes. Ignition is accomplished by a red-hot tube and timing valve, as described in the report on the Society of Arts trials, and the ball governor acts upon the admission valve, cutting off the gas supply when the speed becomes too great. At full power there is an explosion every two revolutions. The diameter of the cylinder is 8·5 inches, and the stroke 18 inches. The trial on 7th December lasted for two hours, the brake horse-power being 11·33, and the revolutions 162·5 per minute. With 71·2 explosions per minute, about three-quarters of the maximum power was thus developed. The principal observations were taken every five minutes, and it was intended to take indicator diagrams at similar intervals, but this was found impossible, owing to the necessity of changing indicator springs when diagrams for the pumping stroke were obtained. There were thus nine diagrams taken each hour with a Crosby indicator and $\frac{1}{160}$ spring (160 lbs. = 1 inch). For the pumping stroke a second Crosby indicator was used, with $\frac{1}{20}$ spring, and both gave reliable diagrams. A copy of the pumping stroke diagram is given at Fig. 152.

In the accompanying tables, the averages for each hour and for the whole

Fig. 152. 1892.

period of two hours are given, and also copies of the indicator diagram nearest to the mean. For the purpose of calculation, a mean diagram, the ordinates of which are the mean of the corresponding ordinates of all the

diagrams taken during the trial, has been constructed (shown by a full line, Fig. 153), and the expansion and compression lines (dotted) have been assumed.

The expansion curve (dotted) corresponds to the equation $p \times v^{1\cdot374} =$ constant, and the compression curve (dotted), $p \times v^{1\cdot302} =$ constant. It will be seen that they both very closely approximate to the actual curves of the mean diagrams.

The net work done with the ideal diagram A, B, C, D, E (see Fig. 153) =

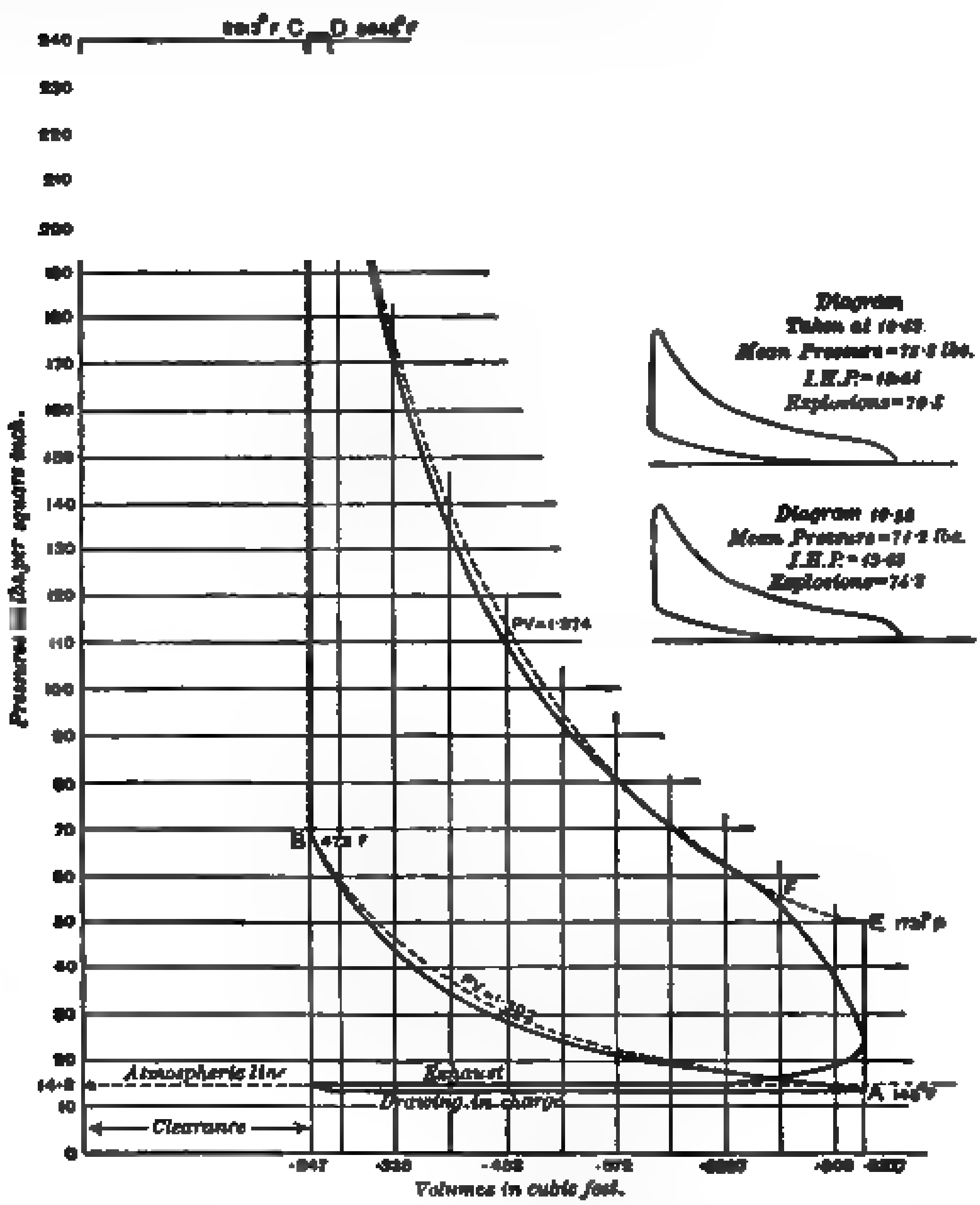


Fig. 153. 1892.

6,594 ft.-lbs. per stroke, as compared with 6,345 ft.-lbs. from the actual indicator diagram.

Indicated Horse-Power.—The mean pressure was 74·56 lbs. during the working stroke, and the corresponding indicated horse-power is 13·69. Allowing for the work expended during the pumping stroke, which corresponds to a mean pressure on the piston of 2 lbs. per sq. in., the net indicated horse-power was 13·32.

Brake Horse-Power.—For absorbing the power, the flywheel was fitted with the usual rope brake, having a weight at one end and a spring balance at the other. A double rope was wound once completely round the circumference of the wheel, and the two portions were kept apart by wooden distance pieces attached to the rope. A little paraffin oil was used occasionally as a lubricant for keeping the wheel cool, and the whole worked very steadily, there being very little fluctuation on the reading of the spring balance. The brake horse-power was, as already stated, 11·33, and corresponds to a mechanical efficiency of $\frac{11\cdot33}{13\cdot32} = 85\cdot06$ per cent. In other words, the B.H.P. was equal to 85 per cent. of the I.H.P.

Gas Consumed.—The gas was measured through a 100-light standard meter, made by Messrs. Alex. Wright & Co. The same meter was employed at the Newcastle and Society of Arts trials.

I.H.P. to drive Engine alone.—This is the difference between the B.H.P. and the I.H.P., and at 162·5 revolutions = 1·99 H.P.

Jacket Water for Cooling the Cylinder.—This was measured by running water through the jacket to waste from two tanks, previously very carefully calibrated. Readings were taken every five minutes on gauge glasses fitted with graduated scales.

Calculations for Air used.—The quantity was not actually measured, but has been determined by the following indirect method:—

The meter temperature being 57°·6 F. and the pressure (1·68 inches of water above atmosphere) = 14·86 lbs. per sq. inch, the specific volume of the gas under these conditions would be—

$$\frac{144\cdot1 \times (57^\circ\cdot6 \text{ F.} + 460^\circ \text{ abs.})}{14\cdot86 \times 144} = 34\cdot87 \text{ cub. ft. per lb.}$$

(144·1 = the difference in ft.-lbs. between the specific heat at constant pressure (K_p) and the specific heat at constant volume (K_v) for London coal gas.)

279·75 cub. ft. were passed through the meter per hour, equal to

$$\frac{279\cdot75 \text{ cub. ft.}}{60 \text{ min.} \times 71\cdot2 \text{ exp.}} = 0\cdot06544 \text{ cub. ft. per explosion (gas).}$$

$$\frac{\cdot06544}{34\cdot87} = \cdot001877 \text{ lb. per explosion (gas).}$$

Assuming that its temperature after admission to the cylinder is = 145° F., or rather higher than the exit temperature of the jacket water (see Table III.), and that its pressure, as shown by the pumping diagrams, was 13·8 lbs. per sq. inch, the gas would then have a specific volume

$$\frac{144\cdot1 \times (145^\circ + 460^\circ)}{13\cdot8 \text{ lbs.} \times 144} = 43\cdot81 \text{ cub. ft. per lb. (gas).}$$

and would occupy a total volume = ·001877 lb. × 43·81
= ·0822 cub. ft. (gas).

The volume of the cylinder + clearance is as follows:—

$$\cdot591 \text{ cub. ft.} + \cdot2467 \text{ cub. ft.} = \cdot8377 \text{ cub. ft.};$$

the volume occupied by the air

$$= \cdot8377 \text{ cub. ft.} - \cdot0822 \text{ cub. ft.} = \cdot7556 \text{ cub. ft.},$$

and its specific volume under the same conditions of temperature and pressure—

$$= \frac{53\cdot35 \times 605^\circ \text{ abs.}}{13\cdot8 \text{ lbs.} \times 144} = 16\cdot25 \text{ cub. ft. per lb.}$$

[53·35 is difference in ft.-lbs. between specific heat at constant volume, K_v 130·20, and specific heat at constant pressure, K_p 183·55 for air.]

$$\therefore \text{ the weight of air present} = \frac{\cdot7556}{16\cdot25} = \cdot0465 \text{ lb.}$$

$$\text{and the total weight of gas + air} \begin{cases} 0\cdot04650 \text{ air.} \\ 0\cdot00188 \text{ gas.} \\ \overline{0\cdot04838 \text{ lb.}} \end{cases}$$

$$\text{The ratio } \frac{\text{air}}{\text{gas}} = \text{by volume } \frac{\cdot7556}{\cdot0822} = \frac{9\cdot188}{1}.$$

$$\text{,,} \quad \text{,,} \quad = \text{by weight } \frac{\cdot0465}{\cdot00188} = \frac{24\cdot775}{1}.$$

After combustion, the specific heat at constant volume (K_v), and specific heat at constant pressure (K_p) will be by Grashof's formulæ—

$$K_p = \frac{\cdot2375 \times 9\cdot188 + \cdot343}{9\cdot188 + \cdot48} \times 772 = 201\cdot75 \text{ ft.-lbs.}$$

$$K_v = \frac{\cdot1684 \times 9\cdot188 + \cdot286}{9\cdot188 + \cdot48} \times 772 = 146\cdot35 \text{ ft.-lbs.}$$

Their difference—

$$(K_p - K_v) = \kappa = 55\cdot40 \text{ ft.-lbs.}$$

and the ratio—

$$\frac{K_p}{K_v} = \gamma = \frac{201\cdot75}{146\cdot35} = 1\cdot3785.$$

Temperatures in Cylinder.—The temperatures calculated on this basis for the several portions of the stroke will then be as follows:—Assuming, as above, a temperature of 145° F. for the gas and air after admission to the cylinder at A on the mean diagram, and taking the pressure given on that diagram, we shall have a temperature at B after compression:—

$$= T = \frac{p \times v}{53\cdot35},$$

if we assume, as is probable, that the mixture behaves in compression approximately as air.

The pressure (p) = 67·8 lbs. × 144 = lbs. per sq. ft., the specific volume

$$(v) = \frac{\cdot2467 \quad \text{(clearance)}}{\cdot04838 \text{ (weight of gas and air)}} = 5\cdot099 \text{ cub. ft. per lb.}$$

$$\therefore T = \frac{67\cdot8 \text{ lbs.} \times 144 \times 5\cdot099 \text{ cub. ft.}}{53\cdot35} = 933^\circ \text{ abs.} = 473^\circ \text{ F.}$$

At C, after heat has been added at constant volume, the temperature will be, with a pressure of 240 lbs. per sq. inch—

$$= \frac{938° \times 240 \text{ lbs.}}{67 \cdot 8 \text{ lbs.}} = 3{,}302° \text{ abs.} = 2{,}842° \text{ F.}$$

At D, where the volume = ·2617 cub. ft., after further reception of heat at constant pressure, the temperature will be

$$= \frac{3302 \times \cdot 2617}{\cdot 2467} = 3{,}503° \text{ abs.} = 3{,}043° \text{ F.}$$

At E, where the pressure on the ideal expansion curve = 48·71 lbs. per sq. inch, and the volume occupied = ·8377 cub. ft., the specific volume of the ·04838 lb. of gas and air

$$= \frac{\cdot 8377 \text{ cub. ft.}}{\cdot 04838 \text{ lb.}} = 17 \cdot 31 \text{ cub. ft. per lb.}$$

$$\therefore \text{ the temperature} = \frac{48 \cdot 71 \text{ lbs.} \times 17 \cdot 31 \times 144}{55 \cdot 4 \ (\kappa \text{ for mixture})} = 2{,}191° \text{ abs.} = 1{,}731° \text{ F.}$$

Heat rejected.—The quantities of heat turned into work, and rejected in the jackets and exhaust will, therefore, be as follows:—

$$13 \cdot 69 \text{ I.H.P.} = \frac{13 \cdot 69 \times 33{,}000}{71 \cdot 2} = 6{,}345 \text{ ft.-lbs. per explosion}$$

turned into work.

Multiplying the water passed through the jackets for each five minutes' interval by the corresponding rise in temperature, the mean value of the heat rejected through the jackets per explosion = 10,825 ft.-lbs.

The heat rejected in the exhaust will evidently be equal to the difference between the internal energy of the gases under conditions E and A, although it must be noted that some portion of the heat thus calculated will pass into the jacket water during release, and will thus be reckoned twice over. The heat account on this basis should, therefore, overbalance.

The heat rejected in exhaust will be—

K_v (2,191° − 605°) × ·04838 lb. = 146·35 (1,586) × ·04838 = 11,245 ft.-lbs. per explosion.

As a check upon this quantity, the reception of heat from B to C at constant volume

= K_v (3,302° − 933°) × ·04838 lb. = 146·35 (2,369) × ·04838 = 16,775 ft.-lbs.

And at constant pressure C to D

= K_p (3,503° − 3,302°) × ·04838 lb. = 201·75 (202) × ·04838 = 1,971 ft.-lbs.

During compression, the heat added will be equal to the difference between the internal energies at the beginning and end of the process

= K_v (for air) (933° − 605°) × ·04838 lb. = 130·2 × 328 × ·04838 = 2,066 ft.-lbs.

The work done during compression where $p\,v^{1\cdot302}$ is constant

$= \frac{p_1 v_1 - p_2 v_2}{n - 1} = \frac{144}{\cdot302} = (67\cdot8 \text{ lbs.} \times \cdot2467 \text{ clearance} - 13\cdot8 \text{ lbs.} \times \cdot8377 \text{ total vol.}) \text{ (where } n = 1\cdot302) = 2{,}465 \text{ ft.-lbs.}$

Adding together the heat received,

$$16{,}775 + 1{,}971 + 2{,}066 = 20{,}812 \text{ ft.-lbs.}$$

and subtracting the total work above zero pressure,

$$6{,}345 \text{ ft.-lbs.} + 2{,}465 \text{ ft.-lbs.} = 8{,}810 \text{ ft.-lbs.},$$

we have $20{,}812 - 8{,}810 = 12{,}002$ ft.-lbs. as the remainder rejected, calculated from D, where expansion commences. During expansion the loss of internal energy

$= K_v\,(3{,}503^\circ - 2{,}191^\circ)\ \cdot04838 \text{ lbs.} = 146\cdot35\,(1{,}312)\ \cdot04838 = 9{,}288 \text{ ft.-lbs.}$

The work done

$= \frac{p_1 v_1 - p_2 v_2}{n - 1}$ where $n = 1\cdot374 = \frac{240 \times (\cdot2617 - 48\cdot71) \times \cdot8377}{\cdot374} \times 144 = 8{,}470$ ft.-lbs.

The difference between these quantities will evidently have been passed into the jacket or lost by radiation, and will, therefore, have to be subtracted from the above 12,002 ft.-lbs., in order to give the internal energy remaining to be disposed of at E.

$12{,}002 - (9{,}288 - 8{,}470) = 11{,}184$ ft.-lbs., as compared with 11,245 ft.-lbs. by direct calculation.

Heat Account.—On the Dr. side of the account we have the heat developed by the perfect combustion of ·001877 lb. of gas per explosion.

In order to determine the calorific value of the gas, samples were taken, under mercury, at intervals throughout the trial, and analysed by Mr. G. H. Huntly, A.R.C.S., of the State Medicine Laboratory, King's College, London. The analysis is given in detail in Table V. The calorific value is shown in the last column of this table. Taking this in round numbers as 19,200 B.T.U. per lb., we have for the perfect combustion of ·001877 lb. of gas per explosion, ·001877 × 19,200 × 772 * = 27,820 ft.-lbs. developed per explosion, and the heat account works out as given in Table V. It will be seen that the Cr. side overbalances the Dr. side by about 2¼ per cent., from the unavoidable double reckoning of a portion of the heat credited to exhaust.

Analysis of Exhaust Gases.—In Table VI. will be found the analysis of the exhaust gases. These were also carefully sampled under mercury. It will be seen that they are quite free from CO, and that the combustion is, therefore, probably complete.

As a check upon the necessarily approximate nature of the sampling, Mr. Huntly has calculated what the exhaust products should be, if combustion takes place with 9·188 volumes of air and 1 volume of the gas analysed above. The result is given in the second column of the same

* 772 = ft.-lbs. per B.T.U. or Joule's Equivalent.

table, and agrees very well as to CO and CO_2 with the actual products found. There is, however, considerable excess of oxygen in the calculated, over the found values of the products. This is probably to be accounted for by the difficulty of obtaining a really average sample. The results are, however, worth recording as a close approximation to accuracy.

The oxygen necessary to convert the known value of the hydrogen to water has been allowed for in the calculation, the analysis having been carried out dry.

Transmission of Heat through Cast-Iron Jacket Wall.—The total heating surface (the internal surface of cylinder plus the clearance)

$$= 740 \text{ sq. inches} = 5{\cdot}14 \text{ sq. ft.}$$

Therefore heat transmitted to jackets per sq. ft. per hour

$$= \frac{10{,}825 \times 71{\cdot}24 \times 60 \times 144}{772 \times 740} = 11{,}660 \text{ B.T.U. per hour.}$$

But transmission probably only takes place during the out stroke, therefore the rate of transmission for the revolutions per hour = 9,750, and the explosions = 4273·5 per hour

$$= \frac{11{,}660 \text{ B.T.U.} \times 9{,}750 \times 2}{4273{\cdot}5} = 53{,}190 \text{ B.T.U. per hour} = 886 \text{ B.T.U. per min.}$$

The cooling surface (external surface in jacket space of cylinder metal)

$$= 926{\cdot}6 \text{ sq. inches} = 6{\cdot}43 \text{ sq. ft.}$$

Therefore the rate of transmission per sq. ft. of cooling surface

$$= \frac{53{,}190 \times 5{\cdot}14}{6{\cdot}43} = 42{,}525 \text{ B.T.U. per hour} = 709 \text{ B.T.U. per sq. ft. per min.}$$

Taking the mean temperature of the jacket water as equal to 90° F., and the temperature of the gases when most of the heat would pass into the jackets, as equal to 2,900° F. the rate of transmission, by formula given by Rankine, should be approximately :—

$$\frac{(2{,}900^\circ - 90^\circ)^2}{160} = 49{,}350 \text{ B.T.U. per hour per sq. ft.}$$

which very closely agrees with the actual rate of transmission as above.

The thickness of the cast-iron cylinder wall is about ¾". The *internal* surface of the cylinder in contact with the hot gases is called the *heating* surface; the *external* surface of the cylinder in contact with the jacket water is called the *cooling* surface.

A graphic diagram is added at Fig. 154, giving on a time basis the following particulars of the trial :—Explosions per minute, revolutions per minute, mean pressure, indicated horse-power, brake horse-power, gas consumption, heat rejected in jacket water, total explosions, total revolutions, total water through jackets, total expenditure of energy in millions of foot-pounds, ignition gas, &c. In another trial, made by Professor Capper on the 2nd November, 1892, on the same engine, with the same load, results were obtained very closely agreeing with those of the present trial.

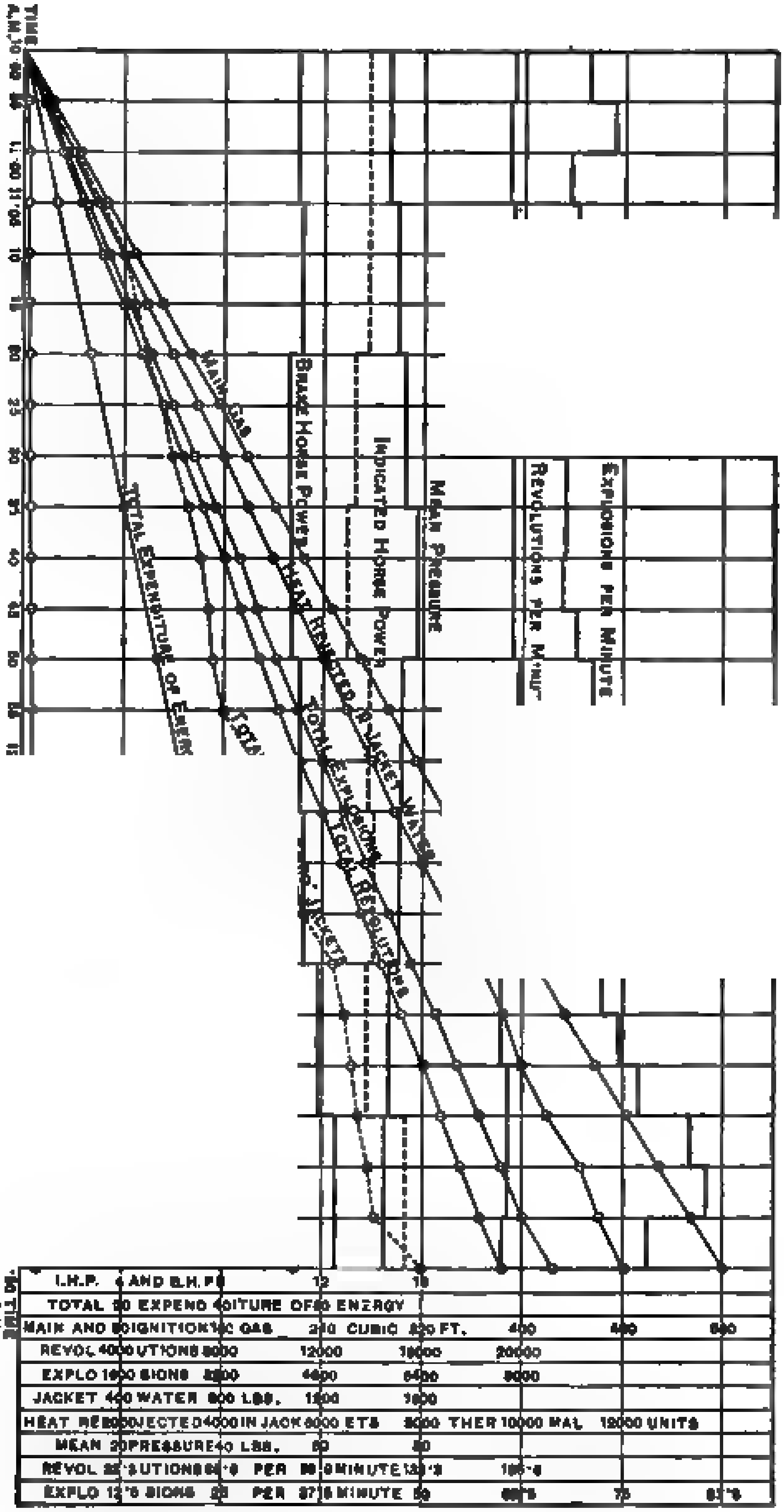


Fig. 154.—Results of Trial on a Time Base—Graphic Representation. 1892.

TABLE I.

RESULTS OF TWO HOURS' TEST ON $8\frac{1}{2}'' \times 18''$ OTTO GAS ENGINE—*London Gas.*

1. Duration of test in hours, . .	1st hour	2nd hour	mean
2. Number of indicator diagrams taken,	9	9	9
3. Average initial pressure above atmosphere in lbs., from mean diagram,	227·5	225·6	226·5
4. Average mean pressure during working stroke from diagram in lbs., .	74·15	74·98	74·56
5. Average mean pressure during pumping stroke in lbs., ...	2	2	2
6. Net average pressure (4 – 5) in lbs.,	72·15	72·98	72·56
7. Revolutions per minute, . . .	162·6	162·4	162·5
8. Explosions per minute by counter, .	69·06	73·42	71·2
9. Indicated H.P. for working stroke,	13·20	14·19	13·69
10. Indicated H.P. net (including pumping stroke), ...	12·85	13·8	13·32
11. Load on rope brake in lbs., . .	202·0	202·0	202·0
12. Reading of spring balance, net lbs.,	71·2	65·3	68·2
Difference, ...	130·8	136·7	133·8
13. Radius of flywheel, ins., . . .	33	33	33
14. Brake H.P., ...	10·96	11·71	11·33
15. Mechanical efficiency of engine, per cent. line 10 and 14, . . .	85·3	84·85	85·06
16. Gas used per hour (without ignition) in cub. ft., ...	271·9	287·6	279·7
17. Gas used per hour (ignition) in cub. ft., ...	5·94	5·96	5·95
18. Total gas used (main and ignition) in cub. ft., ...	277·84	293·56	285·65
19. Pressure of gas at meter, ins. of water, ...	1·7	1·65	1·68
20. Temperature of gas at meter in degrees F., ...	58	58	58
21. Gas per I.H.P. per hour in cub. ft., ...	20·6	20·3	20·45
22. Gas per I.H.P. per hour (including ignition) in cub. ft., . .	21·05	20·69	20·87
23. Gas per brake H.P. per hour in cub. ft., ...	24·8	24·6	24·7
24. Gas per B.H.P. per hour (including ignition) in cub. ft., . . .	25·35	25·17	25·22

TABLE II.

Results of Test—*Continued.*

	1. Town gas used per explosion (volume through meter), ...	·06544 cub. ft.
	2. Pounds gas used per explosion, ...	·001877 lb.
	3. Calorific value of London gas per explosion, calculated from analysis, thermal units, .	36·04 B.T.U.
	4. Mechanical equivalent of ditto, ...	27,820 ft.-lbs.
	5. Work done on charge during compression, .	2,465 ,,
	6. Work done by charge calculated gross, . .	9,059 ,,
	7. Net work done by charge in ideal process, A,B,C,D,E, Fig. 153, ...	6,594 ,,
	8. Actual net work done, mean of all indicator diagrams, ...	6,345 ,,
Efficiencies.	9. Efficiency of engine (actual) $\frac{\text{Heat turned into work}}{\text{Whole heat expended}} = \frac{6,345}{27,820}$ . .	22·8 per cent.
	10. Efficiency of engine (maximum theoretical) $\frac{T_1 - T_0}{T_1} = \frac{3,503° - 605°}{3,503°}$	82·7 ,,
	11. $\frac{\text{Actual efficiency}}{\text{Maximum theoretical efficiency}} = \frac{0·228}{0·827}$ . .	27·5 ,,
Transmission of heat.	12. Rate of transmission of heat through cylinder wall, per sq. ft. (internal) surface per hour, ...	53,190 B.T.U.
	13. Do. do. per sq. ft. (external) surface of cylinder per hour, ...	42,525 ,,
	14. Do. do. per sq. ft. (internal) surface of cylinder per minute, ...	886 ,,
	15. Do. do. per sq. ft. (external) surface of cylinder per minute, ...	709 ,,

TABLE III.

Results of Test—*Continued.* See mean indicator diagram for A,B,C,D,E, Fig. 153, p. 422.

Assumed temperature of gas and air after entering the cylinder (A), ...	145° F.	605° abs.
Calculated temperature after compression (B), .	473° F.	933° ,,
Calculated temperature after reaching maximum pressure (C), ...	2,842° F.	3,302° ,,
Calculated temperature after beginning to fall in pressure (D), ...	3,043° F.	3,503° ,,
Calculated temperature at end of expansion (E),	1,731° F.	2,191° ,,
Mechanical equivalent of heat carried off by jacket water per explosion, . . .	10,825 ft.-lbs.	
Jacket water. In-going temperature, ...	42°·2 F.	
Out-going temperature, . . .	139°·8 F.	
Difference (rise), . . .	97°·6	

TABLE IV.

RESULTS OF TEST—*Continued.* See Indicator Diagrams for A,B,C,D,E, Fig. 153.

		Ft.-Lbs.
Heat taken up by charge during compression, A to B, ...		2,066
,, ,, ,, increase of pressure at constant volume, B to C, ...		16,775
,, ,, ,, increase of volume at constant pressure, C to D, ...		1,971
Total, ...		20,812
Total amount of heat turned into work above zero pressure, ... 6,345 + 2,465 =	8,810	
Heat rejected to jacket during expansion, add	818	
		9,628
Difference = heat rejected in exhaust, .		11,184
Heat rejected in exhaust by direct calculation, ...		11,245

TABLE V.

HEAT BALANCE SHEET.

	Ft.-Lbs. per Explosion.		Ft.-Lbs. per Explosion.
Total heat due to perfect combustion of ·001877 lb. of gas, ...	27,820	Heat turned into work, .	6,345
		,, rejected in jacket water,	10,825
		,, ,, exhaust, .	11,245
	27,820		28,415

PROPORTIONAL VALUES.

	Percentage of whole heat of combustion.
Net work done, ...	22·8
Heat rejected in jacket water, ...	38·9
,, ,, exhaust, ...	40·5
(2·2 per cent. over balance for reasons given)	102·2

TABLE VI.

ANALYSIS OF LONDON GAS USED. (Gas Light and Coke Co.)

	Volume per cent.	Weight in one cub. ft. of gas.	Proportion by weight.	Calorific value per lb.	Calorific value in 1 lb. of gas.
CH_4, ...	31·5	·01408	·4279	23,200 ft.-lbs.	9,928 T.U.
Olefines, $C_2H_4 + C_4H_8$,	5·1	·00599	·1821	21,200 ,,	3,861 ,,
Hydrogen, . . .	51·2	·00286	·0869	52,500 ,,	4,562 ,,
CO, ...	7·7	·00603	·1833	4,300 ,,	788 ,,
Nitrogen, . . .	3·0	·00235	·0714	...	...
CO_2 and Oxygen, .	1·3	·00159	·0484	...	...
	...	·03290	1·0000	...	19,139 T.U.

TABLE VII.

ANALYSIS OF EXHAUST GASES TAKEN AS DRY.

	Per cent. volume.	
	Experiment.	Calculated.
CO_2, Carbon dioxide, ...	6·76	6·45
O_2, Oxygen, ...	6·14	8·94
CO, Carbon monoxide, ...	nil.	nil.
N_2, Nitrogen (by difference), ...	87·10	84·6
By volume, . . .	100·00	100·00

SECTION C.

ABSTRACT TRANSLATION OF BEAU DE ROCHAS' CYCLE.
(French Patent, 1862.)

CONCERNING COMPRESSION IN A GAS ENGINE.

. . . . . . The conditions for perfectly utilising the elastic force of gas in an engine are four in number :—

I. The largest possible cylinder volume with the minimum boundary surface.
II. The greatest possible working speed.
III. Greatest possible number of expansions.
IV. Greatest possible pressure at the beginning of expansion.

The characteristic of gases to disperse over a given area can be turned to excellent account in pipes, but is, on the contrary, evidently an obstacle to the utilisation of the elastic force developed in the gaseous mass. It has been shown [in a former part of the patent] that in pipes the utilisation—that is, the heat transmitted—is in proportion to the diameter of the pipe. In cylinders, therefore, the loss would be in inverse ratio to the diameter, but this only applies to cylinders of very small diameter, and the loss really diminishes more rapidly in proportion to the increase in diameter. Thus the typical design, which, for a given expenditure of gas, assigns a cylinder of the largest diameter, will in this respect utilise the most heat. We may also conclude that, as far as possible, only one gas cylinder should be used in each separate engine.

But the loss of heat in the gas depends also on the time. Other things being equal, the cooling will be greater the slower the speed. Now greater speed seems to entail a cylinder of small volume; but this apparent contradiction disappears if we remember that, for a given consumption of gas, the stroke is not necessarily and invariably limited to the volume of the cylinder.

In utilising the elastic force of gas it is necessary, as with steam, that expansion should be prolonged as much as possible. In the typical design

described above, there is a maximum of expansion for each particular case, although the effect is necessarily limited. The arrangement will, therefore, give the best result, which restores to the motor what may be called its liberty of expansion, that is to say, the power of expanding as much as may be thought desirable, within practical working limits.

Lastly, the utilisation of the elastic force of the gas depends upon a function closely allied to prolonged expansion and its advantages. This is the pressure, which should be as great as possible, to produce the maximum effect. Here the question clearly is to obtain expansion of the gases when they are hot, after compressing them while cold. This is to a certain extent an inverse method of prolonging expansion to that employed when a vacuum is formed. The latter process is not at all suited to gases, because all such compression necessitates an equivalent condensation, and even supposing the gases were combustible, it would be impossible to heat them instantaneously.

Theoretically, therefore, it is possible to utilise the elastic force of the gases without limit, by compressing them indefinitely before heating, just as the elastic force of steam may be utilised without limit, by prolonging expansion indefinitely. Practically an impassable limit is attained, as soon as the elevation of temperature due to previous compression causes spontaneous combustion. If compression be then continued, the work done by it would be represented by expansion prolonged to the same point, less the loss caused by all useless work. The natural limit is here reached, and the arrangement which best attains it will utilise to the most advantage the heat supplied.

The question of heat utilisation being thus stated, the only really practical arrangement is to use a single cylinder, first that the volume may be as large as possible, and next to reduce the resistance of the gas to a minimum. The following operations must then take place on one side of the cylinder, during one period of four consecutive strokes:—

I. Drawing in the charge during one whole piston stroke.

II. Compression during the following stroke.

III. Inflammation at the dead point, and expansion during the third stroke.

IV. Discharge of the burnt gases from the cylinder during the fourth and last stroke.

The same operations being afterwards repeated on the other side of the cylinder in the same number of piston strokes, the result will be a particular type of single-acting, or half-acting engine, so to speak, which will evidently afford the largest possible cylinder, and what is still more important, previous compression. The piston speed will also be greatest in proportion to the diameter, because the work is performed in one single stroke, which would otherwise occupy two. Clearly it is impossible to do more.

As the temperature of the gases coming from a furnace is practically constant, and that of the external atmosphere varies relatively only within narrow limits, the initial temperature of the mixture at the moment of admission into the cylinder will also be practically constant. It will, therefore, be possible to determine the limit of compression at which combustion is produced, and to make the design of the engine conform to it. Thus the maximum effect will always be obtained, for each proportional dilution of the combustible. At the same time there will be no necessity to use electricity, because the starting of the engine being determined by the action of the steam (*sic*), the gases might be admitted only when the speed has become great enough to produce spontaneous inflammation. In any case compression, by helping to mix the charge thoroughly and by raising its temperature, would be favourable to instantaneous combustion. If the initial temperature in the generator corresponded to a pressure of 5 or 6

atmospheres, inflammation would be spontaneously produced if the gases were compressed to about a quarter of the original volume, the effect of loss of heat being neglected. After complete inflammation the pressure would be hardly 30 atmospheres, and as combustion would be effected without excess of air, the pressure would in any other case (*i.e.*, where an excess of air was admitted) be necessarily less. Probably, therefore, in many cases, the absolute limit of utilisation of the heat may be attained.

We may sum up the question by saying that, although the typical arrangement here described can be most completely and perfectly adapted to the utilisation of the elastic force developed by combustion at constant volume in the gaseous mass, it is quite simple. It is perhaps rather a convenience than a necessity to use lift-valve distribution. This is generally the best method, and nothing proves that it may not be applied to the four-cycle type of engine.

SECTION D.

List of Specifications of Patents filed for Gas, Petroleum, and Hot Air Engines for the Year 1884.

				Speciality.
Hargreaves,	325	Jan.	2, 1884,	Valves and general.
Skene,	454	,,	2, ,,	Compressing and igniting.
Steel and Whitehead,	560	,,	3, ,,	Starting and miscellaneous.
Sterne,	1,373	,,	12, ,,	Silencing.
Wirth (Bernstein),	1,457	,,	15, ,,	Producing motive power.
Rodgerson,	2.088	,,	25, ,,	Compression and igniting.
Ainsworth,	2,089	,,	25, ,,	Cylinders.
Ofenderson,	2,135	,,	25, ,,	...
Davy,	3,778	Feb.	2, ,,	Cylinders and valves.
Woodhead,	2,715	,,	5, ,,	Starting and miscellaneous.
Clayton,	2,854	,,	6, ,,	Compression and exhausting.
Fielding,	2,933	,,	8, ,,	,, ,,
Cobham and Gilliespie,	3,495	,,	18, ,,	Noncompression and valves.
Holt and Crossley,	3,537	,,	18, ,,	Starting.
Griffin,	3,758	,,	22, ,,	Cylinder and stuffing boxes.
Holt,	3,893	,,	25, ,,	Compressing pump.
Johnson,	3,986	,,	26, ,,	Igniting.
Malam and King,	4,391	March	5, ,,	General.
Munden,	4,591	,,	8, ,,	Exhausting.
Pollock,	4,639	,,	10, ,,	Igniting and valves.
Wirth (Söhnlien),	4,736	,,	11, ,,	Petroleum motor.
Spencer,	4,776	,,	12, ,,	Exhausting.
Crossley,	4,777	,,	12, ,,	Compression.
Weatherhogg,	4,880	,,	14, ,,	,,
Hill and Hill,	5,007	,,	17, ,,	Igniting, gas or vapour.
Johns and Johns,	5,302	,,	22, ,,	Rotary gas engine.
,, ,,	5,303	,,	22, ,,	,, ,,
J. Magee,	5,365	,,	24, ,,	Valves.
Dewhurst,	5,412	,,	24, ,,	,,
Park,	5,435	,,	25, ,,	Rotary gas engine.
J. Magee,	5,484	,,	26, ,,	Valves.
,,	5,636	,,	29, ,,	,,

			Speciality.
Butcher, ...	5,641	March 29, 1884,	Igniting and valves.
Linford and Piercey, .	5,797	April 1, ,,	Igniting.
Holt, ...	6,039	,, 7, ,,	General.
Wiegand, ...	6,662	,, 22, ,,	Igniting.
Mugniers, ...	6,678	,, 22, ,,	,, and General.
M'Niel, ...	6,784	,, 25, ,,	Tramway loco. (gas).
King, ...	7,284	May 6, ,,	Compression.
,, ...	7,288	,, 6, ,,	,,
Holt, ...	8,211	,, 26, ,,	Compound gas engine.
Sombart, ...	8,232	,, 26, ,,	Compression.
Green, ...	8,489	,, 31, ,,	Supplying gas to engine.
Rogers, ...	8,565	June 4, ,,	Miscellaneous.
Shaw, ...	8,579	,, 4, ,,	Compression.
Crossley, ...	8,637	,, 5, ,,	Igniting (The Otto).
Ainsworth, . . .	8,960	,, 14, ,,	Cylinder.
Guthrie, ...	9,001	,, 16, ,,	Igniting.
Grath (Daimler), .	9,112	,, 17, ,,	Gas or oil motors.
Williamson, Malam, and Ireland, . .	9,167	,, 16, ,,	Valves and gear.
Magee, ...	9,544	,, 28, ,,	Starting.
Welch and Rapier, .	9,645	July 1, ,,	Exhausting.
Capitaine, ...	9,949	,, 9, ,,	Compression.
Norrington, . . .	10,062	,, 11, ,,	Assisting starting.
Guthrie, ...	10,483	,, 16, ,,	Caloric engine.
Shaw, ...	10,885	August 2, ,,	Compression.
Butterworth, . . .	11,086	,, 9, ,,	Noncompression.
Justice, ...	11,361	,, 16, ,,	General.
Crossley, ...	11,578	,, 23, ,,	Igniting.
G. Magee and M'Ghee,	11,596	,, 25, ,,	Gas motor.
Douglas, ...	11,750	,, 29, ,,	Exhausting.
Clark (Hopkins), .	11,837	Sept. 1, ,,	Noncompression and Igniting.
J. Magee, ...	12,023	,, 5, ,,	Igniting.
Griffiths, ...	12,201	,, 9, ,,	,,
Davy, ...	12,264	,, 10, ,,	Cylinders, valves and exhausting.
Brine, ...	12,312	,, 12, ,,	Igniting.
Dougill, ...	12,318	,, 12, ,,	Valves and gear.
Purnell, ...	12,431	,, 15, ,,	Compression.
Hill and Hill, . .	12,603	,, 19, ,,	Noncompression gas or vapour.
Tellier, ...	12,640	,, 20, ,,	General.
Reddie, ...	12,714	,, 23, ,,	,,
Wilson, ...	12,776	,, 25, ,,	Tramway gas engine.
,, ...	12,777	,, 25, ,,	,, ,,
Davy, ...	12,842	,, 26, ,,	Cylinders and valves.
Andrews, ...	13,221	Oct. 6, ,,	General.
Redfern (M'Donough),	13,283	,, 7, ,,	Compression and igniting.
Parker, ...	13,766	,, 17, ,,	,, ,,
Lawson, ...	13,935	,, 21, ,,	Exhausting pump.
Griffin, ...	14,311	,, 29, ,,	Igniting.
Browett, ...	14,341	,, 30, ,,	Exhausting.
Prentice and Prentice,	14,512	Nov. 3, ,,	Starting and igniting.
M'Gillivray, . . .	14,765	,, 8, ,,	Igniting, valves and gear.
Holt and Crossley, .	15,311	,, 20, ,,	Compound gas engine.
Holt, ...	15,312	,, 20, ,,	Compression.
Newton, ...	15,633	,, 27, ,,	,,
Bénier, ...	16,131	Dec. 1, ,,	Hot-air engine.
Holt, ...	16,250	,, 10, ,,	,,

					Speciality.
Atkinson, . . .	16,404	Dec.	13,	1884,	Compression.
Müller (Adkins and Angus), . . .	16,634	,,	18,	,,	Igniting.
Regan, . . .	16,890	,,	24,	,,	Electro gas engine.
Imray (Barnes and Danks), . . .	16,947	,,	27,	,,	Starting.
Radford (Martin), .	16,992	,,	29,	,,	Hot air engine.
Malam and others, .	17,029	,,	30,	,,	Silencing.

List of Specifications of Patents filed for Gas, Petroleum, and Hot Air Engines for Year 1885.

					Speciality.
Johnson (Lenoir), .	610	Jan.	1,	1885,	General and Igniting.
Myer, ...	848	,,	21,	,,	Valves and gear.
Pinkney, ...	1,218	,,	28,	,,	General.
Simon, ...	1,363	,,	30,	,,	Compression.
Asher and Buttress, .	1,424	Feb.	2,	,,	Liquid fuel vapour.
Kempster, ...	1,581	,,	5,	,,	Hydrocarbon.
King, ...	1,700	,,	7,	,,	Compression.
Wright and Charlton,	1,703	,,	7,	,,	Petroleum.
Atkinson, ...	2,712	,,	28,	,,	Valves and gear.
Beechey, ...	3,199	March	11,	,,	Compression and igniting.
Spiel, ...	3,414	,,	17,	,,	Petroleum.
Pope, ...	3,471	,,	17,	,,	Compression.
Holt, ...	3,747	,,	23,	,,	General.
Atkinson, ...	3,785	,,	24,	,,	Compression.
Mackenzie, . . .	3,971	,,	28,	,,	Igniting.
Daimler, ...	4,315	April	7,	,,	Petroleum.
Garrett, ...	4,684	,,	16,	,,	Valves and gear.
Bickerton, ...	5,519	May	5,	,,	General.
Andrews, ...	5,561	,,	6,	,,	Compression and governing.
Mills, ...	5,971	,,	15,	,,	,, ,,
Rigg, ...	6,047	,,	16,	,,	Miscellaneous.
Weatherhogg, . .	6,565	,,	30,	,,	Compression and igniting.
M'Ghee and Magee, .	6,763	June	3,	,,	Miscellaneous ,,
MacGeorge, . . .	6,880	,,	5,	,,	General.
Campbell, ...	6,990	,,	9,	,,	Compression.
Warsop and Hill, .	7,104	,,	11,	,,	Igniting.
Capitaine and Brunler, . . .	7,500	,,	19,	,,	Compression.
Dowson, ...	7,920	,,	30,	,,	Igniting.
Newton, ...	7,929	,,	30,	,,	,, and cylinders and stuffing boxes.
Crossley, ...	8,134	July	4,	,,	Compression and exhausting.
Wordsworth and Wolstenholme, .	8,160	,,	6,	,,	Compression and governing.
Humes, ...	8,411	,,	11,	,,	Hydrocarbon, valves and gear.
Newton (Treeton), .	8,584	,,	15,	,,	Valves, gear and governing.
Sturgeon, ...	8,897	,,	23,	,,	Compression.
Calton (Hortig), . .	9,801	Aug.	8,	,,	Non-compression and exhausting.

					Speciality.
Priestman and Priestman, . .	10,227	Aug.	28,	1885,	Hydrocarbon.
Justice (Hale), . .	10,401	Sept.	2,	,,	Compression, valves and gear.
Daimler, . . .	10,786	,,	11,	,,	Petroleum, road vehicle.
Grading and Harding,	11,215	,,	21,	,,	Igniting.
Redfern (Swyer), .	11,290	,,	22,	,,	Petroleum.
Clark (Economic Motor Co.), . . .	11,294	,,	22,	,,	Non-compression and igniting.
Magee, . . .	11,422	,,	25,	,,	Governing.
Cattrall and Stout, .	11,555	,,	29,	,,	,,
Gillot, . . .	11,558	,,	29,	,,	Compression.
Abel (Gas Motoren-Fabrik Deutz), . .	11,933	Oct.	10,	,,	Igniting.
Southall, . . .	12,424	,,	17,	,,	Compression.
Clark (Economic Motor Co.), . . .	12,483	,,	19,	,,	Igniting.
Schiltz, . . .	12,896	,,	27,	,,	Petroleum.
Grath (Daimler), .	13,163	,,	31,	,,	Gas and oil.
Dinsmore, . . .	13,309	Nov.	4,	,,	Compression, cylinder and stuffing boxes.
Nash, ...	14,394	,,	24,	,,	Liquid fuel vapour.
Burgh and Gray, .	15,194	Dec.	10,	,,	Non-compression and igniting.
Atkinson, . . .	15,243	,,	11,	,,	Starting.
Ruckteshell, . .	15,475	,,	16,	,,	Nitro cellulose.
Johnson and others, .	15,710	,,	21,	,,	Governing.
Rogers, . . .	15,737	,,	22,	,,	Compression and igniting.
Bickerton, . . .	15,845	,,	24,	,,	Starting and compression.
Willcox, . . .	15,874	,,	24,	,,	Hot air ,, ,,
,, . . .	15,875	,,	24,	,,	Cylinder and stuffing boxes.
,, . . .	15,876	,,	24,	,,	,, ,,
Wimshurst, . .	15,936	,,	28,	,,	General design.

Specifications of Patents filed for Gas, Petroleum, and Hot Air Engines for the Year 1886.

					Speciality.
Johnson and others, .	11	Jan.	1,	1886,	Electric ignition.
Butterworth, . .	207	,,	6,	,,	Compression and valves.
Fairweather, . .	477	,,	12,	,,	Hot air and gas mixed.
,, . .	478	,,	12,	,,	,, ,,
Nash, . . .	493	,,	12,	,,	Double acting.
Magee, . . .	665	,,	15,	,,	Valves for exhausting.
Brine, . . .	942	,,	21,	,,	Road vehicle.
Priestman and Priestman, . . .	1,394	,,	30,	,,	Hydrocarbon.
M'Ghee, . . .	1,433	Feb.	1,	,,	Igniting and valves.
Humes, . . .	1,464	,,	1,	,,	Hydrocarbon and igniting.
Welch and Rook, .	1,696	,,	5,	,,	General design.
Shillito, . . .	1,797	,,	6,	,,	Cooling cylinders.
Haddan, . . .	1,958	,,	10,	,,	General design and valves.
Eimecke, . . .	2,122	,,	13,	,,	Hot air and valves.
Capitaine and Brunler,	2,140	,,	13,	,,	Petroleum.

					Speciality.
Skene, . . .	2,174	Feb.	15,	1886,	Igniting.
Leigh, . . .	2,272	,,	16,	,,	Regulating supply of gas.
Shaw, . . .	2,447	,,	19,	,,	Igniting and valves.
Boulton and Perrett, .	2,653	,,	23,	,,	Gas and steam, opposite sides.
Millburn and Hannan,	2,993	March	3,	,,	Miscellaneous and governing.
Deacon, . . .	3,010	,,	3,	,,	Hot air, valves and gear.
Fielding, . . .	3,402	,,	10,	,,	Double cylinder and igniting.
Davy, . . .	3,473	,,	11,	,,	Isolating walls of cylinder.
Atkinson, . . .	3,522	,,	12,	,,	General design.
Neil, ...	4,234	,,	26,	,,	Varying volume of gas mixtures.
Dawson, . . .	4,460	,,	30,	,,	Double and single acting.
Hutchinson, . .	4,785	April	6,	,,	Petroleum.
Justice, . . .	4,881	,,	7,	,,	Combined gas engine and water pump.
Abel, ...	5,804	,,	28,	,,	General design and valves.
Humes, . . .	5,597	,,	24,	,,	Hydrocarbon, and to prevent back ignition.
Bernardi, . . .	5,665	,,	24,	,,	Igniting.
Benz, ...	5,789	,,	28,	,,	Petroleum vehicle.
Redfern, . . .	6,161	May	6,	,,	Gas producer and motor.
Leigh, . . .	6,165	,,	6,	,,	Valves and gear.
Charlton and Wright,	6,551	,,	5,	,,	Petroleum and igniting.
Gilliespie, . . .	6,612	,,	17,	,,	Valves.
Nash, ...	6,670	,,	18,	,,	Cylinders and stuffing boxes.
Rollason, . . .	7,427	June	2,	,,	,, ,,
Nixon, . . .	7,658	,,	8,	,,	Double piston.
Butterworth, . .	7,936	,,	15,	,,	Combustible gas motor.
Reed, ...	7,967	,,	15,	,,	Hot air.
Roots, . . .	8,210	,,	22,	,,	Petroleum and ignition.
Weatherhogg, . .	8,436	,,	26,	,,	Petroleum, ignition, and valves.
Fielding, . . .	9,563	July,	23,	,,	Ignition.
Johnson, . . .	9,598	,,	24,	,,	Carburetter for gas engine.
Beeker, . . .	9,704	,,	27,	,,	Hot gases and steam.
Crowe and Crowe, .	9,727	,,	28,	,,	Gas caloric.
Stuart, . . .	9,866	,,	31,	,,	Combining explosive fluids.
Otto, ...	9,941	Aug.	3,	,,	Furnace by compressed air.
Oke, ...	10,034	,,	5,	,,	Hot air.
Boys and Cuningham, . .	10,332	,,	12,	,,	Silencer.
Schiltz, . . .	10,480	,,	16,	,,	Petroleum and igniting.
Boyd, . . .	11,246	Sept.	4,	,,	Internal combustion.
Humes, . . .	11,269	,,	4,	,,	Hydrocarbon and starting.
Boult, . . .	11,576	,,	11,	,,	General and carburetter.
Turnbull, . . .	11,833	,,	17,	,,	Manufacturer of gas for motors.
Hutchinson, . .	12,068	,,	22,	,,	Petroleum (Swan design).
Butterworth, . .	12,134	,,	24,	,,	General design.
Robinson, . . .	12,346	,,	29,	,,	Hot air.
Rollason, . . .	12,368	,,	29,	,,	Miscellaneous and mixture.
Sutcliffe, . . .	12,640	Oct.	5,	,,	Utilising waste heat.
Nobilings, . . .	12,883	,,	9,	,,	Caloric and valves.
Clerk, . . .	12,912	,,	11,	,,	Petroleum and valves.

				Speciality.
Humes, . . .	13,229	Oct.	16, 1886,	Hydrocarbon.
Macallam, . . .	13,517	,,	22, ,,	Propulsion of vessels by explosion.
Ruckhill, . . .	13,655	,,	25, ,,	Guards for flywheels.
Newton (Murray), .	13,727	,,	26, ,,	General design, igniting and valves.
Daimler, . . .	14,034	Nov.	1, ,,	Marine propulsion by gas or petroleum.
M'Ghee, . . .	14,578	,,	11, ,,	Miscellaneous.
Collier, . . .	15,066	,,	19, ,,	Internal combustion, hydrocarbon.
Robson, . . .	15,307	,,	24, ,,	General design.
Stuart and Binney, .	15,319	,,	24, ,,	Hydrocarbon and starting.
Taylor, . . .	15,327	,,	24, ,,	General design, valves and gear.
Southall, . . .	15,472	,,	26, ,,	Miscellaneous.
Wordsworth and Wolstenholme,	15,507	,,	27, ,,	Hydrocarbon.
,, ,,	15,507a	,,	27, ,,	,,
Griffin, . . .	15,764	Dec.	2, ,,	Shut off gas supply, automatic.
Hearson, . . .	15,955	,,	6, ,,	Utilising vapour.
Priestman and Priestman, . .	16,779	,,	21, ,,	Varying charges, hydrocarbon engine.

Specifications of Patents filed for Gas, Petroleum, and Hot Air Engines for the Year 1887.

				Speciality.
Sterry, ...	125	Jan.	4, 1887,	Varying stroke of gas engine.
Boulton and Perrett, .	459	,,	11, ,,	Steam and hot air.
Newall, ...	516	,,	12, ,,	Petroleum.
Lake, ...	807	,,	18, ,,	Hot air.
Abel, ...	847	,,	19, ,,	Ignition.
Hosack, ...	888	,,	20, ,,	Heat engine.
Charter, Galt, and Tracy, . . .	1,168	,,	25, ,,	Cylinders and pistons.
Abel, ...	1,189	,,	25, ,,	Quadruple cylinders.
Bénier, ...	1,262	,,	26, ,,	Hot air.
Adam, ...	1,266	,,	28, ,,	Petroleum.
Priestman and Priestman, . .	1,454	,,	29, ,,	Hydrocarburetted.
Lynam, ...	1,683	Feb.	2, ,,	Heat engine.
Pinkney, ...	1,986	,,	2, ,,	Gas Hammer.
Haddan, ...	2,194	,,	11, ,,	Cylinders and electric ignition.
Bamford, ...	2,236	,,	12, ,,	Lubricants for gas engines.
Thomas, ...	2,368	,,	15, ,,	Pistons.
Jones, ...	2,477	,,	17, ,,	Hot air.
Browett and Lindley, .	2,520	,,	17, ,,	Electric ignition.
Tellier, ...	2,631	,,	19, ,,	Gas locomotive.
Knight, ...	2,783	,,	22, ,,	Hydrocarbon.

						Speciality.
Koeber, . . .	2,844	Feb.	24,	1887,		Caloric engine.
Spiel, ...	3,109	,,	28,	,,		Hydrocarbon
Griffin, . . .	3,350	March	4,	,,		Pistons and stuffing boxes.
Redfern, . . .	3,660	,,	10,	,,		Fluid pressure motor.
Schmidt, . . .	3,705	,,	11,	,,		Compressed air and steam.
Griffin, . . .	3,934	,,	15,	,,		Charges of mixtures.
Beechey, . . .	4,160	,,	19,	,,		Gas bags to regulate supply.
Ross and M'Dowall, .	4,403	,,	24,	,,		Rotary engine and pumps.
Redealgh, . . .	4,511	,,	26,	,,		Enclosed crank chamber.
Sington, . . .	4,564	,,	28,	,,		Tram and vehicles.
Howard, Howard and Lloyd, . . .	4,692	,,	29,	,,		Hot air.
Casper, . . .	4,757	,,	30,	,,		Utilising heat after explosion.
Stevens, . . .	4,843	,,	31,	,,		Combined gas and compressed air.
Sturgeon, . . .	4,923	April	2,	,,		Double piston,
Wallwork, . . .	4,940	,,	2,	,,		Lubricating.
Johnson, . . .	5,095	,,	5,	,,		Igniting.
Bernhardt, . . .	5,336	,,	12,	,,		Regulating.
Hargreaves, . .	5,485	,,	15,	,,		Thermodynamic engine.
Crossley, . . .	5,833	,,	21,	,,		Combined gas and dynamo.
Priestman and Priestman, . .	5,951	,,	23,	,,		Hydrocarbon and valves.
Koerting, . . .	5,981	,,	25,	,,		Valves and governing.
Dawson, . . .	6,501	May	3,	,,		Cylinders, governing and igniting.
Faber, . . .	7,350	,,	20,	,,		Cylinders, valves and ignition.
Davy, ...	7,677	,,	25,	,,		Piston and twin gas engines.
Wastfield, . . .	7,771	,,	28,	,,		Cylinder and valves.
Wallwork and Sturgeon, . .	7,925	June	1,	,,		Adjustable ports.
Johnson, . . .	8,182	,,	7,	,,		Propelling by reaction of explosion.
Wastfield, . . .	8,466	,,	13,	,,		Low pressure or vacuum motor.
Beechey, . . .	8,818	,,	18,	,,		Cylinders and valves.
Lewis, . . .	8,883	,,	22,	,,		Valves.
Haddan, . . .	9,111	,,	27,	,,		Petroleum.
,, . . .	9,461	July	4,	,,		Air engine.
Kühne, . . .	9,506	,,	5,	,,		Hot air and motive power.
Duevettet, . . .	9,717	,,	11,	,,		Oil for gas engine.
Hahn, . . .	10,176	,,	20,	,,		Carburetter.
Bull and Bull, . .	10,202	,,	21,	,,		Gas and steam.
Dougill, . . .	10,360	,,	25,	,,		Piston, slides and governing.
Griffin, . . .	10,460	,,	27,	,,		Twin engines.
Tennent, . . .	11,201	Aug.	16,	,,		Heating air.
Justice, . . .	11,255	,,	17,	,,		General design, and electric ignition.
Lindley and Browett, .	11,345	,,	19,	,,		Valves.
Abel, ...	11,444	,,	22,	,,		Ignition.
Wordsworth, . .	11,466	,,	23,	,,		Hydrocarbon.
Abel, ...	11,503	,,	23,	,,		Cylinders and valves.
Niel and Bennett, .	11,567	,,	25,	,,		Hydrocarbon.
Embleton, . . .	11,717	,,	29,	,,		Cylinders and ignition.
Atkinson, . . .	11,911	Sept.	2,	,,		Varying expansion.

				Speciality.
Abel, ...	12,187	Sept.	8, 1887,	Reservoir of gas and air.
Priestman and Priestman, . .	12,432	,,	13, ,,	Hydrocarbon.
Lane, ...	12,591	,,	16, ,,	Power to vehicles by compressed air.
Hearsons, . . .	12,592	,,	16, ,,	Vaporising hydrocarbons.
List and others, . .	12,696	,,	19, ,,	Petroleum motor.
Boult, ...	12,749	,,	20, ,,	Oil and electric ignition.
M'Dowall, . . .	12,758	,,	20, ,,	Sight feed lubricators for gas engine.
Koerting, . . .	12,863	,,	22, ,,	Valves and ignition.
Lea, ...	13,436	Oct.	4, ,,	Starting gas engines.
Knight, . . .	13,555	,,	6, ,,	Ignition for hydrocarbon engine.
Davy, ...	13,916	,,	13, ,,	Supply to motors.
Barker, . . .	14,027	,,	15, ,,	Admission and ignition.
Middleton, . . .	14,048	,,	17, ,,	Varying stroke.
Hutchinson, . .	14,269	,,	20, ,,	Jackets for vaporising oil.
Schmidt and Beekfeld,	14,952	Nov.	2, ,,	Cylinders and valves.
Crossley and Anderson,	15,010	,,	3, ,,	Ignition.
Butler, ...	15,598	,,	15, ,,	Hydrocarbon for vehicles.
Davy, ...	15,658	,,	15, ,,	Oil jacketed cylinders.
Williams, . . .	16,029	,,	22, ,,	Cylinders and pistons.
,, . . .	16,144	,,	24, ,,	Cylinders and ignition.
Ravel and Brecttmayer,	16,257	,,	26, ,,	Cylinders and valves.
Sturgeon, . . .	16,309	,,	28, ,,	Cylinders and pistons.
Abel, ...	17,108	Dec.	12, ,,	Motor engine by gas, vapour, or spray.
Wallwork and Sturgeon, . .	17,353	,,	17, ,,	Governing.
Bickerton, . . .	17,686	,,	23, ,,	Starting by water motor.
Abel, ...	17,896	,,	29, ,,	Ignition, tubes heated.

SPECIFICATIONS OF PATENTS FILED FOR GAS, PETROLEUM, AND HOT AIR ENGINES FOR THE YEAR 1888.

				Speciality.
Priestman and Priestman, . .	270	Jan.	6, 1888,	Starting hydrocarbon engines.
Rogers, ...	281	,,	7, ,,	Compressed air.
Sington, ...	512	,,	12, ,,	Gas and petroleum.
Johnson, ...	600	,,	14, ,,	Hot air.
Abel, ...	688	,,	16, ,,	Igniting.
Imray, ...	1,336	,,	28, ,,	Starting gas and tram engines.
Blessing, . . .	1,381	,,	30, ,,	Hydrocarbon for tram engines.
Crossley, . . .	1,705	Feb.	4, ,,	Compound gas or oil motor.
Butler, ...	1,780	,,	6, ,,	Hydrocarbon.
,, ...	1,781	,,	6, ,,	,,
Quack, ...	2,466	,,	18, ,,	Gas, vapour, or air.
Cole, ...	2,467	,,	18, ,,	Cranks longer than cylinder, gas and other engines.
Windhausen, . .	2,549	,,	21, ,,	Expanding air and gases.

					Speciality.
Johnson, . . .	2,804	Feb.	24,	1888,	Cylinders and valves for admission and exhaust.
,, . . .	2,805	,,	24,	,,	Starting gear.
Ochelhauser, . .	2,913	,,	27,	,,	Rapid combustion in gas engine.
Abel, ...	3,020	,,	28,	,,	Gas, vapour, or air.
,, ...	3,095	,,	29,	,,	Igniting gas or oil motor engine.
M'Ghee and Burt, .	3,427	March	6,	,,	Governing and sun and planet motion.
Rollason and Hamilton, . .	3,546	,,	7,	,,	Starting, governing, and reservoir.
Crossley, . . .	3,756	,,	10,	,,	Ignition and valves.
Gaze, ...	3,964	,,	14,	,,	Compress gas and air and store separately.
Turner, . . .	4,057	,,	16,	,,	Compressed air for motor.
Bourne, . . .	4,531	,,	24,	,,	Hydrocarbon.
Crossley, . . .	4,624	,,	26,	,,	Valves and governing gear.
Wilson, . . .	4,944	April	3,	,,	Gas engine and producer.
Lake, ...	5,204	,,	7,	,,	Ignition for gas and petroleum.
Tavernier and Casper,	5,628	,,	16,	,,	Gas and steam.
Humes, . . .	5,632	,,	16,	,,	Hydrocarbon.
Abel, ...	5,724	,,	17,	,,	Petroleum.
Rowden, . . .	5,774	,,	18,	,,	Increased efficiency of gas, &c., engines.
Lake, ...	5,914	,,	20,	,,	Hydrocarbon.
Gaze, ...	6,036	,,	23,	,,	Compressing gas and air separately.
Thompson, . . .	6,088	,,	24,	,,	Production of carburetted air.
Wells and others, .	6,108	,,	24,	,,	Hot air motor.
Tellier, . . .	6,212	,,	26,	,,	Producing cold by waste heat.
Karylynski, . .	6,468	May	1,	,,	Gas and air motor for vehicles.
Wordsworth, . .	7,521	,,	22,	,,	Hydrocarbon.
Browett and Lindley, .	7,547	,,	22,	,,	Valves for hydrocarbon engine.
Schnell, . . .	7,893	,,	30,	,,	Hydrocarbon.
Stubbs, . . .	7,927	,,	30,	,,	,,
Southall, . . .	7,934	,,	30,	,,	Cylinders, valves, and second shaft gas engine.
Nelson, . . .	8,009	June	1,	,,	Hydrocarbon and igniting.
Johnston, . . .	8,252	,,	6,	,,	Cylinders and pistons, gas or vapour.
Kosztovito, . .	8,273	,,	6,	,,	Cylinders for gas or hydrocarbon and locomotives.
De Boutteville and Malandin, . .	8,300	,,	6,	,,	Starting.
Altman, . . .	8,317	,,	7,	,,	Prevention of premature explosion in petroleum.
De Boutteville and Malandin, . .	9,249	,,	25,	,,	Governor for gas and other engine.
Roots, . . .	9,310	,,	26,	,,	Piston and second explosion chamber.
,, . . .	9,311	,,	26,	,,	Generator to hydrocarbon.

				Speciality.
Dougill, . . .	9,578	July	2, 1888,	Timing motion of valve for admission, &c.
Abel, ...	9,602	,,	2, ,,	Valve for gas or hydrocarbon.
Knight, . . .	9,691	,,	4, ,,	Hydrocarbon.
Rawden, . . .	9,705	,,	4, ,,	Arrangement of cranks.
Purnell, . . .	10,165	,,	12, ,,	General design.
Nash, . . .	10,350	,,	17, ,,	General design and ignition.
Giffard, . . .	10,645	,,	23, ,,	Compressed air motor.
Binney and Stuart,	10,667	,,	24, ,,	Hydrocarbon.
Campbell, . . .	10,748	,,	25, ,,	General design.
Hargreaves, .	10,980	,,	30, ,,	Combustion thermomotor.
Piers, . . .	10,983	,,	30, ,,	Hot air, compressed do., and gas for tram loco.
,, ...	10,984	,,	30, ,,	Starting tram loco., with air, gas, &c.
Roots, . . .	11,067	,,	31, ,,	Hydrocarbon.
Morris and Wilson,	11,161	Aug.	1, ,,	Generator for gas and hydrocarbon.
Barker, . . .	11,242	,,	3, ,,	Valves and governing.
Purchas and Freund,	11,614	,,	11, ,,	Hydrocarbon.
Ellis, ...	11,847	,,	16, ,,	Hot air, gas, or steam.
Hargreaves, .	12,361	,,	28, ,,	Thermomotors.
Charon, . . .	12,399	,,	28, ,,	Variable expansion and igniting.
Wells, . . .	13,206	Sept.	12, ,,	Hot air.
Boult, . . .	13,414	,,	17, ,,	Cylinders, pistons, valves, and cranks.
Stuart and Binney,	14,076	Oct.	1, ,,	Hydrocarbon.
Crossley and Holt,	14,248	,,	3, ,,	Starting.
Abel, ...	14,349	,,	5, ,,	Ignition, gas or oil.
Hearsons, . . .	14,401	,,	6, ,,	Charging and ejection of spent charges.
Royston, . . .	14,614	,,	11, ,,	Heat engine.
Williams, . . .	14,831	,,	16, ,,	Governing.
Richards, . . .	15,158	,,	22, ,,	Hydrocarbon.
Thompson, . . .	15,448	,,	27, ,,	Carburetter to gas engine.
Boult, . . .	15,840	Nov.	2, ,,	Petroleum.
,, . . .	15,841	,,	2, ,,	Ignition.
,, . . .	15,845	,,	2, ,,	Keeping walls cool.
,, . . .	15,846	,,	2, ,,	Friction clutch for gas engines.
Jensen, . . .	15,858	,,	2, ,,	Braking and restarting.
Roots, . . .	15,882	,,	3, ,,	Starting petroleum engine.
Lindley and Browett,	16,057	,,	6, ,,	Hydrocarbon.
Simon, . . .	16,183	,,	8, ,,	Cylinder and piston.
Roots, . . .	16,220	,,	9, ,,	Governing and starting.
Lalbin, . . .	16,268	,,	9, ,,	Multiple cylinder and ignition.
Menzies, . . .	16,605	,,	15, ,,	Piston rings.
Koerting, . . .	17,167	,,	26, ,,	Valve for gas or petroleum.
Schmidt, . . .	17,343	,,	28, ,,	Steam and air.
Crossley and Anderson,	17,413	,,	28, ,,	Ignition, oil or gas.
Shaw, . . .	18,377	Dec.	17, ,,	General design.
Davies, . . .	18,516	,,	18, ,,	Utilising waste heat of gas engine.
Nichols, . . .	18,707	,,	21, ,,	Obtaining variable speed.
Hargreaves, .	18,761	,,	22, ,,	Thermomotor.
Pinkney, . . .	19,013	,,	29, ,,	General design.

Specification of Patents filed for Gas, Petroleum, &c. Engines for the Year 1889.

					Speciality.
Boult, ...	121	Jan.	3,	1889,	Distributing mechanism.
Robinson, . . .	298	,,	8,	,,	Hot air.
Paton, ...	441	,,	10,	,,	Starting.
Taylor, ...	708	,,	15,	,,	Double cylinder, and general design.
Repland, ...	875	,,	17,	,,	Second cylinder for charge, greater volume.
Wells, ...	1,593	,,	29,	,,	Hot air, combination cylinder and chamber.
Tavernier and Schlesinger, . .	1,603	,,	29,	,,	Hydrocarbon, jacketed cylinder.
Thompson, . . .	1,831	Feb.	1,	,,	Slide valves for gas engines.
Peebles, ...	1,957	,,	4,	,,	Double-acting gas engine.
Ketchem, ...	1,977	,,	4,	,,	Generation of steam and gases.
Field, ...	1,997	,,	4,	,,	Hot air and gases.
Piers, ...	2,144	,,	6,	,,	Locomotion by gas or petroleum.
Davenport and Horsley, . . .	2,587	,,	14,	,,	Pistons for gas engines.
Miller, ...	2,637	,,	14,	,,	Petroleum vapour or gas, general design.
Gardie, ...	2,649	,,	14,	,,	Gas engine and generator.
Adams, ...	3,331	,,	25,	,,	Explosion reservoir.
Pinkney, ...	3,525	,,	27,	,,	Working gear of gas engines.
Williams, ...	3,820	March	5,	,,	Double-acting gas engines.
Roots, ...	3,972	,,	6,	,,	General improvements.
Schmidt, ...	4,237	,,	11,	,,	Mixed steam and gas motors.
Phillips, ...	4,302	,,	12,	,,	Hot air.
Von Ochelhauser, .	4,710	,,	18,	,,	Ignition of variable mixture of gas.
Schemmings, . . .	4,796	,,	19,	,,	Superheating steam, by inflammable gas.
Southall, ...	5,072	,,	23,	,,	Oil or gas combination, reservoir and cylinder.
Lake, ...	5,165	,,	26,	,,	Propulsion of vessel by explosion engine.
Millet, ...	5,199	,,	26,	,,	Propulsion of vehicles and aerial do. by gas engine.
Theevman, ...	5,301	,,	28,	,,	Charging cylinder, gas, vapour and hydrocarbon.
Nelson and M'Millan, .	5,397	,,	29,	,,	Valves and governing.
Abel, ...	5,616	April	2,	,,	Reversing mechanism.
Bánki and Csonki, .	6,296	,,	12,	,,	Valve motion.
Priestman and Priestman, . .	6,682	,,	18,	,,	Hydrocarbon.
Cordenons, . . .	6,748	,,	20,	,,	Rotary gas, petroleum, or steam.
Knight, ...	6,831	,,	24,	,,	Vaporiser for engines by oil.

					Speciality.
Tavernier and Casper,	7,069	April,	27,	1889,	Cooling cylinder of gas engine.
Tellier, . . .	7,140	,,	29,	,,	Producing combustible gases for power.
Sumner, . . .	7,522	May	6,	,,	Ignition by electricity.
,, . . .	7,533	,,	6,	,,	Ignition by incandescent platinum.
Crowe and Crowe, .	7,594	,,	7,	,,	Gas or hydrocarbon, general design.
Sergeant, . . .	7,605	,,	7,	,,	Valves for steam and air engines.
Lawson, . . .	7,640	,,	7,	,,	General design.
Weatherhogg, . .	8,013	,,	14,	,,	Petroleum and general design.
Imray, . . .	8,778	,,	27,	,,	Supplying petroleum to engines.
Clerk, . .	8,805	,,	28,	,,	Double piston for gas engines.
Lake, ...	8,886	,,	28,	,,	Hot air.
Butler, . . .	9,203	June	3,	,,	Multiple cylinder, Petroleum.
Hunt and Howden, .	9,685	,,	12,	,,	Reaction wheel, by combustible gas or vapour.
Roots, . . .	9,834	,,	15,	,,	Hydrocarbon.
Daimler, . . .	10,007	,,	18,	,,	Gas and petroleum motors.
Wells and Clarke, .	10,144	,,	21,	,,	Hot air.
Rogers and Wharry, .	10,286	,,	24,	,,	General design.
Bull, ...	10,634	July	1,	,,	Petroleum or other explosive generator.
Rowden, . . .	10,669	,,	2,	,,	Link connection for gas engines.
Leigh, . . .	10,831	,,	5,	,,	Compound gas or petroleum.
Wastfield, . . .	10,850	,,	5,	,,	Petroleum or other hydrocarbon.
White and Raphael, .	11,038	,,	9,	,,	General design.
Williams, . . .	11,162	,,	11,	,,	Tube for igniting.
Hartley, . . .	11,395	,,	16,	,,	Hydrocarbon vaporiser and air heater.
Dheyne, . . .	11,459	,,	17,	,,	Generating gas from combustible liquid.
Bull, ...	11,926	,,	26,	,,	Admission passages and valves for gas, air, or vapour.
Allison, . . .	12,045	,,	30,	,,	Combined carburetter and gas engine.
Hoelljes, . . .	12,447	Aug.	6,	,,	Methods of operating gas engines.
Thompson, . . .	12,472	,,	7,	,,	Combination of cylinder and pumps.
Lanchester, . .	12,502	,,	7,	,,	Governing, gas and other motive power.
Middleton, . .	13,431	,,	26,	,,	Gas and steam power tricycle.
M'Allen, . . .	13,572	,,	28,	,,	Gas or oil motor.
Bennett, . . .	14,154	Sept.	7,	,,	Motive power from carbonic oxide.
Huntington, . .	14,592	,,	17,	,,	Vehicles, by vapour engines.
Hargreaves, . .	14,789	,,	19,	,,	Thermomotor.

				Speciality
Binney and Stuart,	14,868	Sept.	20, 1889,	Hydrocarbon.
Diederichs,	14,926	,,	21, ,,	Combustible vapour engine.
Willcox,	14,927	,,	21, ,,	Hot air.
M'Tighe,	15,805	,,	24, ,,	Conversion of heat into motive power.
Spurway,	15,295	,,	28, ,,	Hot air and other gas.
Green,	16,202	Oct.	15, ,,	General arrangement.
Lindemann,	16,391	,,	17, ,,	Valve arrangement.
Hamilton and Rollason,	16,434	,,	18, ,,	Gas or vapour, general design.
Haedicke,	17,008	,,	28, ,,	Combined gas, and steam engine.
Boult,	17,024	,,	28, ,,	Petroleum.
Niel,	17,295	,,	31, ,,	Valves, ports, governing and lubricating.
Lowne,	17,344	Nov.	1, ,,	Atmospheric engine.
Abel,	18,746	,,	22, ,,	Igniting gas or oil motor engine.
Schmidt,	18,813	,,	23, ,,	Steam and air motors.
Barrett and Daly,	18,847	,,	23, ,,	Electric igniter.
Schmidt,	19,124	,,	28, ,,	Combined steam and hot air.
Lanchester,	19,868	Dec.	10, ,,	Valves and governing.
Lindley and Browett,	20,033	,,	12, ,,	Hydrocarbon.
Ford,	20,115	,,	13, ,,	Rotary gas engine.
Duerr,	20,161	,,	14, ,,	Gas or petroleum motor.
Frederking and Schubert,	20,166	,,	14, ,,	Valve gear for gas, steam, &c.
Crist and Covert,	20,249	,,	17, ,,	Igniters and general design.
Atkinson,	20,482	,,	20, ,,	Internal combustion heat engine.
Clark,	20,512	,,	20, ,,	Throttle valve for gas and other engines.
Snelling,	20,703	,,	24, ,,	Rotary gas, steam, or air engine.
Jenks,	20,748	,,	24, ,,	Governors for gas and other engines.
Abel,	20,892	,,	30, ,,	Regulating speed of gas or oil motors.

Specification of Patents filed for Gas, Petroleum, and Hot Air Engines for the Year 1890.

				Speciality.
Mewburn,	132	Jan.	3, 1890,	Air motor.
Mannesman,	837	,,	16, ,,	Compressed air and combustible fluid.
Bedford and Rodger,	1,064	,,	21, ,,	Metallic packing.
Linder,	1,150	,,	22, ,,	Petroleum, general design.
Tavernier,	1,586	,,	29, ,,	Cylinders and pistons.
Abel,	1,943	Feb.	5, ,,	Petroleum, general design.
Scollary,	2,207	,,	11, ,,	Regulating gas supply.

					Speciality.
Touche,	2,384	Feb.	13,	1890,	Petroleum igniting by liquid petroleum.
Lake,	2,647	,,	18,	,,	Combination of cylinders.
,,	2,648	,,	18,	,,	Air engine.
Grob and others,	2,914	,,	24,	,,	Petroleum motor, air to inlets.
Munden,	3,128	,,	27,	,,	Speed varying gear.
Abel,	4,164	March	17,	,,	Governing, gas and petroleum.
Binns,	4,362	,,	20,	,,	Additional cylinders, pistons, and ignition.
Kaselowsky,	4,574	,,	24,	,,	Petroleum and gas, inlets and ignition.
Otto,	4,823	,,	27,	,,	General improvement for regular working.
Baxter,	5,005	,,	31,	,,	Gradual mixture outside cylinder.
Meluish,	5,192	April	3,	,,	Gas and petroleum, compound engine.
Otto,	5,273	,,	5,	,,	Regulating gas or oil motors.
,,	5,275	,,	5,	,,	Mixture of atmospheric air and of oil.
Lanchester,	5,479	,,	10,	,,	Starting.
Mayer,	5,787	,,	16,	,,	Cylinders and pistons.
Dheyne and others,	5,933	,,	18,	,,	Petroleum and gas, general design.
Otto,	5,972	,,	19,	,,	Ignition and regulating.
Hamilton,	6,015	,,	21,	,,	Gas or vapour motor, general design.
Otto,	6,113	,,	22,	,,	Supplementary cylinder, piston, and valve.
Griffin,	6,217	,,	23,	,,	Combustible gases for motors.
Dawson,	6,407	,,	26,	,,	Reciprocating and rotary, *no valves*.
Donington,	6,910	May	5,	,,	Double cylinders, position and angle of.
Fielding,	6,912	,,	5,	,,	General design.
Butler,	6,990	,,	6,	,,	Hydrocarbon, general design.
Stuart and Binney,	7,146	,,	8,	,,	Vaporiser direct to cylinder.
Mewburn,	7,177	,,	8,	,,	Combined gas and compressed air motor.
Johnson,	7,626	,,	16,	,,	Engine, sector of sphere, and separate chamber for combustion, &c.
Sykes and Blamiris,	7,830	,,	20,	,,	Conversion of solid into gaseous fuel.
Popp,	8,322	,,	29,	,,	Compressed air motor and heating stove thereof.
Seage and Seage,	8,431	,,	31,	,,	Lever, gear for valves.
Robson,	9,496	June	19,	,,	Double pistons, unequal strokes.
Butterfield,	9,769	,,	24,	,,	Lubricators.
Wilkinson,	10,051	,,	28,	,,	Producing carburetted air for motors.
Beechey,	10,089	,,	30,	,,	Piston valves.

					Speciality.
Williams, . . .	10,137	July	1,	1890,	Obtaining motive power by explosion.
Stuart, . . .	10,293	,,	3,	,,	Obtaining power from ammonia and compressed air.
Vogelsang and Hille, .	10,642	,,	9,	,,	Valve gear for petroleum and gas engines.
Grob, Shutze, and others, . .	10,718	,,	10,	,,	Ignition of gas, petroleum, and vapour engines.
Griffin, . . .	10,952	,,	14,	,,	Valves for regulating and governing.
Lake, ...	11,062	,,	15,	,,	Hydrocarbon, general design.
Wells and others, .	11,174	,,	17,	,,	Recovery of heat from steam and hot air.
Richardson and Norris,	11,755	,,	28,	,,	Ignition and other valves for gas or vapour.
Schiersand, . .	11,834	,,	29,	,,	Governor.
Pollitt, . . .	12,111	Aug.	2,	,,	Converting heat into mechanical energy.
Holt, ...	12,314	,,	6,	,,	Supply, exhaust, and governing oil motors.
Stuart, . . .	12,472	,,	9,	,,	Compound, hydrocarbon, & reciprocating cylinder.
M'Ghee and Burt, .	12,690	,,		,,	Collapsible reservoir, governing and igniting.
Justice, . . .	12,678	,,	13,	,,	Motor, general, for road and tram cars.
Stallairt, . . .	12,760	,,	14,	,,	Charging device, fulminate for ignition.
Vermand, . . .	13,019	,,	19,	,,	Compression of air in special cylinder.
Stuart, . . .	13,051	,,	20,	,,	Rotary engine
Ovens and Ovens, .	13,352	,,	25,	,,	Ignition, valves, and cooling.
Offen, ...	13,594	,,	29,	,,	Combination of cylinders and pistons.
Hall, ...	14,382	Sept.	12,	,,	Ignition.
Roots, . . .	14,549	,,	16,	,,	Double explosion, second explosion chamber.
Robinson, . . .	14,787	,,	19,	,,	Operating, valves.
De Boutteville and Malandin, .	14,900	,,	20,	,,	Governing, regulating, and valves.
Redfern, . . .	15,063	,,	23,	,,	Hot air, high pressure.
Hartley, . . .	15,309	,,	27,	,,	Hydrocarbon vaporiser.
Vivian, . . .	15,479	,,	30,	,,	Hot air, general design.
Dheyne and others, .	15,525	Oct.	1,	,,	Copper and nickel, coils in connection with gas, &c., engines.
,, ,, .	15,526	,,	1,	,,	Conversion of liquid hydrocarbon into gas.
Campion and Woods, .	15,807	,,	6,	,,	Utilisation and combustion of hydrocarbon gases.
Stuart and Binney, .	15,994	,,	8,	,,	Chamber highly heated for ignition.
Cruickshank, . .	16,301	,,	14,	,,	General design.
Pinkney, . . .	17,167	,,	27,	,,	Gas or petroleum, general design.

						Speciality.
Mattershead,	17,299	Oct.	29,	1890,	Compound cylinder, hollow valves, combining passages and ignition, &c.
Higginson,	17,371	,,	30,	,,	Loose piston controlled by compressed air.
Sayer,	18,161	Nov.	11,	,,	Gaseous pressure, apparatus for producing motion.
Griffin,	18,401	,,	14,	,,	Igniting in hydrocarbon or petroleum.
Boult,	18,645	,,	18,	,,	Governors.
Kaselowsky,	19,171	,,	25,	,,	Igniting devices.
Lanchester,	19,513	Dec.	1,	,,	Ignition and starting, gas or hydrocarbon.
Roots,	19,559	,,	1,	,,	Prevention of leakage in petroleum, &c.
Lobet,	19,791	,,	4,	,,	Distributing device for valves.
Griffin,	19,962	,,	6,	,,	Forming combustible spray of air and finely divided hydrocarbon.
Albrecht,	20,226	,,	11,	,,	Gas generator and motor combined.
Holt,	20,888	,,	22,	,,	Water jacket and tank for uniform temperature.
Lentz and others,	21,165	,,	29,	,,	Single acting engine, general design.

Specifications of Patents filed for Gas, Petroleum, and Hot Air Engines for the Year 1891.

					Speciality.
Pinkney,	103	Jan.	2,	1891,	Position of valves, and ignition, hydrocarbon.
Carling,	110	,,	3,	,,	Governing gas and other engines.
Gray,	191	,,	5,	,,	Producing explosive mixture, hydrocarbon.
Bickerton,	227	,,	6,	,,	Prevention of noise by intake of air.
Bickerton,	297	,,	7,	,,	Governing.
Boult,	383	,,	8,	,,	Valve gear for gas or petroleum.
Kehlberger and Fougue,	458	,,	9,	,,	Areo-hydro-thermo engine.
Adams,	741	,,	15,	,,	Rotary engine.
MacCallum,	816	,,	16,	,,	Heat engine fluid piston.
Miller,	834	,,	16,	,,	Petroleum vaporiser and cylinder combined.
Williams,	970	,,	20,	,,	Combination of cylinder, piston and valves.
Robinson,	1,083	,,	21,	,,	Governing.
Williams,	1,299	,,	24,	,,	Timing opening, &c., of ignition valves and starting.

						Speciality.
Weatherhogg, . .	1,447	Jan.	27,	1891,	Hydrocarbon vaporiser.
Abel, ...	1,903	Feb.	2,	,,	Valves for gas and petroleum engines.
Gray, ...	2,053	,,	4,	,,	Vaporiser for hydrocarbon.
Rouzay, . . .	2,815	,,	16,	,,	Gas and petroleum, general design.
Hughes, . . .	2,976	,,	18,	,,	Rotary, three cylinders rotate.
Weiss, . . .	3,261	,,	23,	,,	Production of combustible vapour from petroleum, &c.
Coffey, . . .	3,350	,,	24,	,,	General design.
Rockhill, . . .	3,669	,,	28,	,,	Flywheel guards for gas engines.
Wertenbrach, . .	3,682	,,	28,	,,	Pistons, double movable rings.
Priestman and Priestman, . .	3,830	March	3,	,,	Admission of cold air to heated charge.
Trewhella, . . .	3,948	,,	5,	,,	Utilising residue of gases exploded.
Dawes, . . .	4,004	,,	6,	,,	Starting.
Fenby, . . .	4,024	,,	6,	,,	Valves for hydro and fluid pressure machines.
Priestman and Priestman, . .	4,142	,,	7,	,,	Hydrocarbon separating jacket into two parts.
Lanchester, . .	4,222	,,	10,	,,	Governing by use of magnet.
Campbell, . . .	4,355	,,	11,	,,	Distributing combustible mixture.
Griffin, . . .	4,535	,,	13,	,,	Regulating and governing.
Cooper, . . .	4,771	,,	17,	,,	Ignition.
Vanduzen, . . .	5,158	,,	23,	,,	Gas and gasoline engine, general design.
Love and Priestman, .	5,250	,,	24,	,,	Using liquefiable gas for cooling jackets.
Higginson, . . .	5,490	,,	28,	,,	Treble cylinder.
Fachris, . . .	5,663	April	1,	,,	Explosive engine, by powder, "Gatling" system.
Skene, . . .	5,747	,,	3,	,,	Anti-fluctuator and regulator for gas, &c.
Bickerton, . . .	6,090	,,	9,	,,	Igniting and starting.
Day, ...	6,410	,,	14,	,,	Enclosed crank, and impulse every revolution.
Barclay, . . .	6,578	,,	16,	,,	Double-acting, cylinder closed each end.
Ridealgh and Welford,	6,598	,,	17,	,,	Simple gas engine, general design.
Abel, ...	6,717	,,	18,	,,	Supplying oil, &c., at constant pressure.
Rennes, . . .	6,727	,,	18,	,,	Petroleum motor, for road cars, &c.,
Key, ...	6,949	,,	22,	,,	Discharge of gases.
Purnell, . . .	7,047	,,	23,	,,	Governor for gas or oil motor.
Altman, . . .	7,157	,,	25,	,,	,, ,,
Pinkney, . . .	7,313	,,	28,	,,	Conical combustion chamber and ignition.

					Specialty.
Horn, ...	8,032	May	9,	1891,	Simple gas engine, general design.
Capitaine, . . .	8,069	,,	11,	,,	Combination of valves to inlet.
Barrett and Ticehurst,	8,251	,,	14,	,,	Starting gas engine by cartridges of explosives.
Hardingham, . .	8,289	,,	14,	,,	Rotary gas engine.
Abel, ...	8,469	,,	16,	,,	Drawing in and expelling air for expansion.
Shillito, . . .	8,821	,,	25,	,,	Igniting tube for petroleum motors.
Boult, . . .	9,006	,,	27,	,,	Improved gas or petroleum engine, general design.
Southall, . . .	9,038	,,	28,	,,	Valves for charging, &c.,
Day, ...	9,247	June	1,	,,	Simple gas engine, run either way.
Bosshardt, . . .	9,268	,,	2,	,,	Governors and valves.
Huesler, . . .	9,323	,,	2,	,,	Gasifying contrivance for petroleum motors.
Hawkins, . . .	9,805	,,	10,	,,	Vibrating gas engine.
Withers and Covert, .	9,931	,,	11,	,,	,, ,,
Crossley and Holt,	10,298	,,	17,	,,	Regulating supply of oil to oil motors.
Fiddes and Fiddes,	10,333	,,	18,	,,	Second piston at back end.
Irgens, . .	11,132	,,	30,	,,	Petroleum and gas motor and producer.
Pinkney, . .	11,138	,,	30,	,,	Petroleum combustion and igniting chamber.
Held, . . .	11,628	July	8,	,,	Gas pressure regulator for engines.
Kaselowsky, .	11,680	,,	9,	,,	Valve motion, petroleum engine, and generator.
Wellington, .	11,851	,,	13,	,,	Imperishable igniting tube.
Lanchester, .	11,861	,,	13,	,,	Starting gas motors.
Settle, . .	12,330	,,	21,	,,	Boat or tram propulsion by gas.
Clerk,. . .	12,413	,,	22,	,,	Operating valves.
Menard, . .	12,981	,,	31,	,,	Firing charges by magnetism, dynamo, and Ruhmkorff coil.
,, . .	12,981	,,	31,	,,	...
King, . . .	14,002	Aug.	19,	,,	Cylinders, pistons, igniting and exhausting mechanism.
Weyman and Drohe, .	14,133	,,	21,	,,	Regulating supply of oil to hydrocarbon.
Watkinson, .	14,134	,,	21,	,,	Improvement in thermo-dynamo machine for gas, &c., motors.
Huelser, . .	14,269	,,	24,	,,	Link motion for opening valves.
Abel, . . .	14,519	,,	27,	,,	Igniting apparatus for oil or gas.
Hoffman, . .	14,865	Sept.	2,	,,	Hot air, general design.
Lanchester, .	14,945	,,	4,	,,	Governors.
Williams, . .	15,078	,,	7,	,,	Starting.
Clerk,. . . .	16,404	,,	28,	,,	Valve details.
Hornsby and Edwards,	17,073	Oct.	7,	,,	Mixing hydrocarbon with air, petroleum motor.

				Speciality.
Evers, . . .	17,364	Oct.	12, 1891.	Automatic valves.
Abel, ...	17,724	,,	16, ,,	Valve apparatus controlling charges, &c.
Evans, . . .	17,815	,,	17, ,,	Simple gas engine, rotary valve.
Pinkney, . . .	17,955	,,	20, ,,	Igniter for gas or petroleum engine.
Shaw and Asworth, .	18,020	,,	21, ,,	Better utilisation of pressure in gas engines.
Walch, Darrington, and others, . . .	18,276	,,	24, ,,	Valve gear.
Field, ...	18,503	,,	27, ,,	Improvement of engine worked by hot gases, such as air, &c.
Roots, . . .	18,621	,,	29, ,,	Valve gear for internal combustion engine.
Weyman and others, .	18,640	,,	29, ,,	Prevention of overheating in gas engines.
Earnshaw and others,	18,715	,,	30, ,,	Valves of gas engines.
Clerk, ...	18,788	,,	31, ,,	Starting gear.
Roots, . . .	19,275	Nov.	7, ,,	Improvement in hydrocarbon, &c., engines.
Barron, . . .	19,318	,,	9, ,,	Conversion of slide gas engines to tube igniters.
Fielding, . . .	19,517	,,	11, ,,	Starting.
Johnson, . . .	19,772	,,	14, ,,	Feed pumps for petroleum engine.
,, . . .	19,773	,,	14, ,,	Means to regulate temperature of evaporation in petroleum engine.
Ridealgh, . . .	19,811	,,	16, ,,	Sealed chamber and flexible partition in gas or petroleum motors.
Robinson, . . .	20,262	,,	21, ,,	Gas engine, general design.
,, . . .	20,745	,,	28, ,,	Gas engine, cooling.
Perrollaz, . . .	20,845	,,	30, ,,	Lubricators for gas engine.
Knight, . . .	20,926	Dec.	1, ,,	Vaporiser for petroleum and heavy hydrocarbons.
Weyman and others, .	21,015	,,	2, ,,	Ignition, cooling, and vaporiser for hydrocarbon.
Lanchester, . .	21,406	,,	8, ,,	Operating valves and governing.
Hartley and Kerr, .	21,496	,,	9, ,,	Governing gas engine.
Miller, . . .	21,529	,,	9, ,,	Valve gear, specially exhaust.
Leigh, . . .	22,559	,,	24, ,,	Utilisation of gases before expelled from cylinder.
,, . . .	22,559	,,	24, ,,	,, ,,
Burt, ...	22,578	,,	28, ,,	Starting, stopping, and reversing gas and vapour engines.
Seck, ...	22,834	,,	31, ,,	Simple gas or hydrocarbon engine.
Abel, ...	22,847	,,	31, ,,	Combination of vaporiser and explosion chamber of hydrocarbon and oil motors.

Specifications of Patents filed for Gas, Petroleum, and Hot Air Engines for the Year 1892.

					Speciality.
Richardson and Norris,	112	Jan.	4,	1892,	Starting gas and vapour engines.
Edwards, . . .	260	,,	6,	,,	Heating uniformly mixtures of air and gas.
Krank, . . .	435	,,	8,	,,	Utilisation of air or other gas for power.
Higginson, . . .	520	,,	11,	,,	Double piston, explosion between.
Wilkinson, . . .	524	,,	11,	,,	Mixing vapour of benzoline with coal gas.
Rankin and Rankin, .	826	,,	15,	,,	Hydrocarbon mixing and vaporising.
Simon, . . .	926	,,	16,	,,	Starting gas or petroleum engines.
Thompson, . . .	1,075	,,	19,	,,	Controlling power of engine.
Southall, . . .	1,203	,,	21,	,,	Discharge valve for gas or oil motor.
Brooks and Holt, .	1,246	,,	22,	,,	Water jacket of gas and vapour engine.
Richardson and Norris,	1,768	,,	29,	,,	Valve and operating valves of gas and vapour engine.
Schwarz, . . .	1,814	,,	29,	,,	Starting and storing power.
Barker, . . .	1,879	Feb.	1,	,,	Gas bags for gas engines.
Atkinson, . . .	2,181	,,	4,	,,	Self starting gas and vapour engine.
,, . . .	2,492	,,	9,	,,	Internal combustion engine, general design.
Swiderski, . . .	2,495	,,	9,	,,	Distribution of inflammable vapour and air.
Abel, ...	2,728	,,	11,	,,	Operating valves for regulating gas and oil motors.
Leigh, . . .	2,854	,,	13,	,,	Supplying liquid hydrocarbon, igniting, and governing.
Crossley and Bradley,	2,862	,,	13,	,,	Starting and igniting gas or oil motors.
Jonstone, . . .	3,047	,,	16,	,,	Oscillating cylinder, gas or oil.
Harris, . . .	3,165	,,	18,	,,	Tubes for igniting gas or petroleum.
Pinkney, . . .	3,203	,,	18,	,,	Starting large gas engines.
Czermak, . . .	3,292	,,	19,	,,	Single acting, cooled by air.
Humpudge and Snoxall,	3,417	,,	22,	,,	Lubricating and starting gas engine.
Robert, . . .	3,574	,,	23,	,,	Cylinder divided in three compartments.
Stuart and Binney, .	3,909	,,	29,	,,	Regulating temperature of vaporiser of hydrocarbon.
Bickerton, . . .	4,078	March	2,	,,	Governor.
Hamilton, . . .	4,189	,,	3,	,,	Valves and governing.

				Speciality.
Lanchester, . . .	4,210	March	3, 1892,	Governing and igniting.
Bell and Richardson, .	4,347	,,	5, ,,	Portable petroleum engine.
Richardson and Norris,	4,352	,,	5, ,,	Petroleum engine combustion chamber.
Lanchester, . . .	4,374	,,	5, ,,	Operating valves and governing.
Richardson and Norris,	4,375	,,	5, ,,	Supplying oil for petroleum and liquid fuel engines.
Clerk, ...	5,445	,,	19, ,,	Governor and valve gear.
Bilbault, ...	5,740	,,	23, ,,	Gas and petroleum, general design.
Michels, ...	5,819	,,	24, ,,	Feeding devices for petroleum motors.
Bell and Richardson, .	5,972	,,	28, ,,	Semi-portable, petroleum or liquid fuel engine.
Owen, ...	6,240	,,	31, ,,	Gas and hydrocarbon, general design.
Chatterton, . . .	6,284	April	1, ,,	Method of employing steam and gas for motors.
Morani, ...	6,655	,,	6, ,,	Mechanism for distribution and mixing air and gas.
Adams, ...	6,828	,,	9, ,,	Rotary for steam, air, or gas.
Shillito, ...	6,872	,,	9, ,,	Petroleum motor, valves and vaporiser.
Dawson, ...	6,952	,,	11, ,,	Gas engine combustion chamber, part of cylinder.
Courtney, ...	7,047	,,	12, ,,	Petroleum motor, supply of air and valves.
Diesel, ...	7,241	,,	14, ,,	Producing motive work by heated air, combustion of gases, or mixture of same.
Sennett and others, .	7,943	,,	27, ,,	Utilisation of steam and gases for obtaining power.
Hornsby and others, .	8,128	,,	29, ,,	Piston, cylinder, heating air, and jacketing valve box.
Pollock, ...	8,401	May	4, ,,	Governor and trip mechanism.
Beugger, ...	8,538	,,	5, ,,	Cooling gas or hydrocarbon engine.
Johnson, for L. Genty,	8,678	,,	7, ,,	Aerothermic engine, general.
Griffin, ...	8,733	,,	9, ,,	Heating igniting apparatus.
Guillery, ...	9,121	,,	13, ,,	Rotary.
Robinson, ...	9,161	,,	14, ,,	Governor and mixing valve.
Beugger, ...	9,439	,,	18, ,,	Portable gas or petroleum motor.
Ogle, ...	9,448	,,	18, ,,	Igniting charges in cylinder.
Magee, ...	9,674	,,	21, ,,	Igniting apparatus, and general improvements.
Richert, ...	10,019	,,	26, ,,	Heating air to increase energy of same, in air, &c., engines.
Seck, ...	10,091	,,	27, ,,	Improvements in hydrocarbon motors.

				Speciality.
Hamilton, . . .	10,254	May	30, 1892,	Valves operating or governing gas or oil motors.
Holt, ...	10,437	June	1, ,,	Igniting for gas or oil motors.
Hersey, . . .	10,639	,,	4, ,,	Producing gas for motive power from decomposition of ammonium, nitrate, and a hydrocarbon.
Weyman and others, .	11,141	,,	14, ,,	Regulating temperature of vaporiser in hydrocarbon motor.
O'Kelly, . . .	11,598	,,	21, ,,	Tramcar gas motor.
Hitchcock, . .	11,708	,,	22, ,,	Secondary ignition tube, &c., for hydrocarbon motors.
Webb, . . .	11,928	,,	27, ,,	Differential pistons, &c.
Clerk, . . .	11,936	,,	27, ,,	Starting gear for gas engines.
Hornsby and others, .	11,962	,,	27, ,,	Jacketing vaporiser and combustion chamber.
Anderson, . . .	12,165	,,	30, ,,	Compound cylinders and pistons.
Boult, for Charter, .	12,183	,,	30, ,,	Special gas engine.
Davy, . . .	13,077	July	16, ,,	Cylinders.
Johnson, for Hille, .	13,088	,,	16, ,,	Apparatus for producing mixture of air and petroleum.
Abel, for Gas Motoren-Fabrik Deutz, .	13,859	,,	19, ,,	Discharge and supply valves operated by cams.
V. Ochelhauser and Junker, . . .	14,317	Aug.	8, ,,	Pistons moving in opposite directions.
Hogg and Forbes, .	14,650	,,	12, ,,	Igniting and governing.
Susini, . . .	14,711	,,	15, ,,	Motor by ether or other volatile liquid.
,, . . .	14,712	,,	15, ,,	Motor by ether in combination with steam.
,, . . .	14,713	,,	15, ,,	Motor by ether vapour.
Piers, . . .	15,247	,,	24, ,,	Combination of cylinders.
Weyman, . . .	15,417	,,	27, ,,	Improved vaporiser.
Spathe, . . .	16,245	Sept.	10, ,,	Hot air motor, general.
Griffin, . . .	16,339	,,	13, ,,	Valves to control supply of hydrocarbon.
Brigg, . . .	16,365	,,	13, ,,	Lubricator for gas, &c., engine.
Brünler, . . .	16,379	,,	13, ,,	Invention for gasifying petroleum.
,, . . .	16,380	,,	13, ,,	Rotary petroleum motor.
,, . . .	16,381	,,	13, ,,	Combination of passages in petroleum motor.
,, . . .	16,382	,,	13, ,,	Cooling arrangements for gas and oil motors.
Redfern, . . .	16,413	,,	13, ,,	Hot air motor, general.
Whittaker, . . .	16,986	,,	23, ,,	Ignition tubes.
Andrews and others, .	17,277	,,	28, ,,	Governing gas, oil, or similar motors.
Fairfax, . . .	17,391	,,	29, ,,	Petroleum motor, no valves.
Hartley and Kew, .	17,427	,,	30, ,,	Compound gas engines.
Held, . . .	17,632	Oct.	4, ,,	Fire engine propelled by portable oil motor.

						Speciality.
Southall, . . .	18,020	Oct.	10,	1892,		Valve arrangement for gas and oil motors.
,, . . .	18,109	,,	11,	,,		Gas engine.
Russell, . . .	18,118	,,	11,	,,		Special divided cylinder.
Cock, ...	18,513	,,	15,	,,		Passages opened by pistons.
Strok, . . .	18,808	,,	20,	,,		Reservoir for petroleum motor.
Mein, ...	19,054	,,	24,	,,		Pneumatic motor.
M'Kenzie and Handyside, . . .	20,088	Nov.	8,	,,		Governing gear.
Ryland, . . .	20,413	,,	11,	,,		Compound, double, and triple cylinder.
Weyman and others, .	20,660	,,	15,	,,		Utilising heat taken up by cooling the cylinder.
Andrews and others, .	20,802	,,	17,	,,		Lubricating piston, and preventing jacket water freezing.
,, ,, .	20,803	,,	17,	,,		Ignition.
Priestman Bros., .	21,342	,,	23,	,,		Starting hydro-carburetted engine.
Crouan, . . .	21,389	,,	23,	,,		Hot air engine.
Enger, . . .	21,475	,,	24,	,,		Gas or other motor, general design.
Altman, . . .	21,534	,,	25,	,,		Spray apparatus for hydro-carburetted air engine.
Winckler, . . .	21,857	,,	30,	,,		Feeding oil engines.
,, . . .	21,858	,,	30,	,,		Reversing gear for oil engines.
Weller, . . .	21,917	,,	30,	,,		Igniting.
Durr, ...	21,952	Dec.	1,	,,		Hydrocarbon motor.
Weyman and others, .	22,797	,,	12,	,,		Transmitting and reversing gear.
Roots, . . .	23,786	,,	24,	,,		Heating air for petroleum engine.
Sennett and Durie, .	23,800	,,	24,	,,		Cooling, heating, and lubricating cylinder.
Best, ...	24,065	,,	30,	,,		Gas motor, vehicles.

Specifications of Patents filed for Gas, Petroleum, and Air Engines for the Year 1893.

Fielding, ...	108	Jan.	3,	1893,	Double cylinders.
Wetter, for Gerson and Sachse, . . .	153	,,	4,	,,	Varying strength of explosive charge.
Shuttleworth, A. & F.,	531	,,	10,	,,	Furnace lamps for oil or gas engine.
Sabatier and others, .	608	,,	11,	,,	General construction.
Abel, for Gas Motoren-Fabrik Deutz, .	735	,,	12,	,,	Combination of two four-cycle cylinders.
Shiels, ...	779	,,	13,	,,	Automatically regulating the temperature of cooling water.
Dawson, ...	1,070	,,	17,	,,	Heating igniting surface and lubricating.
Burt and M'Ghee, .	1,277	,,	20,	,,	Compound, tandem type.
Dixon, ...	2,110	,,	31,	,,	Combination of secondary cylinder, tandem type.

					Speciality.
Mellon and Reid, .	2,523	Feb.	4,	1893,	Deodorising exhaust from gas and oil motors.
Lanyon, . . .	2,596	„	6,	„	Hydrocarbon motor, cylinder variable diameter.
Evans, . . .	2,788	„	8,	„	Balance valves.
Weyman, . . .	2,912	„	9,	„	Lamp and vaporiser for oil motor.
Imray, for Kames, .	3,273	„	14,	„	Compressed air locomotive and heated air reservoir.
Hartley and Kerr, .	3,332	„	15,	„	Double-acting impulse, both sides of piston.
Davy, . . .	3,401	„	15,	„	Double cylinder, communicating, twin type.
Hartley and Kerr, .	3,971	„	23,	„	Compound, increasing efficiency in low-pressure cylinder.
Willis, H. & V., .	4,382	„	28,	„	Fluid pressure engine.
Bellamy, . . .	4,564	March	2,	„	Ignition secondary tube.
Davy, . . .	4,696	„	3,	„	Combination of cylinders for working and compressing.
Rollason, . . .	5,005	„	8,	„	Prevention of bursting of water-jacketed cylinder.
Lake, for Baekeljau, .	5,256	„	10,	„	Explosive gas actuating pump.
Trewhala, . . .	5,456	„	14,	„	Internal corrugated walls of cylinders.
Walker and Bedford, .	5,935	„	20,	„	Combined electric and compressed air.
Bellamy, . . .	6,093	„	22,	„	Reservoir supplied with explosive mixture.
Sayer, . . .	6,204	„	23,	„	Explosive and pressure fluid turbine.
Okes, ...	6,453	„	27,	„	Regulating charges of air.
Berk, ...	6,534	„	28,	„	Compound, for gas or oil.
Owen, . . .	7,023	April	5,	„	Vapour burner and oil reservoir.
Bellamy, . . .	7,064	„	6,	„	Compound tandem, "side rods."
Walker, . . .	7,292	„	6,	„	Exhaust scrubber for petroleum.
Dawson, . . .	7,426	„	11,	„	Pump with compound plunger.
List and others, . .	7,433	„	11,	„	Vaporiser for petroleum or oil.
Burt, ...	7,466	„	12,	„	Improvement in variable speed and reversing.
Knapper and Marton,	8,020	„	20,	„	Atmospheric vacuum engine, general.
Morcom, . . .	8,095	„	21,	„	Compound tandem and direct-acting pump.
Lindahl, . . .	8,158	„	22,	„	Admission valves for petroleum and other motors.
Wilkinson, . .	8,409	„	26,	„	Combination of two or more cylinders, enclosed.
Drake, ...	8,639	„	29,	„	Vaporiser in connection with cylinder cover.
Robinson and Robinson,	8,864	May	3,	„	Cams and eccentrics to actuate valves.
Crouan, . . .	8,967	„	4,	„	Actuating exhaust and governing.

				Speciality.
Abel, for Gas Motoren-Fabrik Deutz,	9,181	May	8, 1893,	Discharge valves.
Okes,	9,216	„	9, „	Cylinder with two pistons.
Brackert and Debattue,	9,549	„	12, „	Rotary motor, also pump.
Roots,	9,618	„	13, „	General arrangement of working.
Abel, for Gas Motoren-Fabrik Deutz,	10,274	„	24, „	Valve gear for gas and petroleum motors.
Hartley and Kerr,	10,310	„	24, „	Starting gas engine by aid of steam.
Peebles,	10,801	June	2, „	Valves, anti-pulsating and governing.
Grove,	12,330	„	23, „	Heating lamps to hydrocarbon engines.
Dougill,	12,427	„	24, „	Valves and valve arrangements.
Drysdale,	12,600	„	27, „	Valves and atomising apparatus for hydrocarbon.
Morgan,	12,732	„	29, „	Converting oil into spray centrifugally.
Priestman Bros.,	12,843	„	30, „	Exposing jacket water to cooling action of air.
Pullen,	12,917	July	1, „	Oil, spirit, gas, or steam motor.
Furnival,	13,281	„	7, „	Reversing gear.
„	13,282	„	7, „	Starting apparatus.
Fiddes, A. & F.,	13,518	„	12, „	Construction of cylinders and piston.
Smethurst and others,	14,212	„	22, „	Applying combustible mixture of air and gas.
Bickerton,	14,454	„	27, „	Starting by extra cylinder and intermediate valve.
Boult, Cie. Niel,	14,546	„	28, „	Automatically starting and stopping.
Hornsby and Edwards,	14,558	„	28, „	Double valve box and vaporiser.
Thompson, for Durr,	14,572	„	29, „	Vaporiser for petroleum motor.
Boult, for Société Crebessac,	14,891	Aug.	3, „	Operating admission and exhaust valves by single cam.
Millar,	14,949	„	4, „	Locomotive oil motor, general.
Campbell,	15,199	„	9, „	Vaporiser and valve oil motor.
Bellamy,	15,359	„	12, „	Travelling crane, gas or hydrocarbon.
Foyer,	15,405	„	12, „	Valve gear for regulating admission of gas and air.
Boult, for Brauer and others,	15,900	„	22, „	Rotary engine or pump.
Sims,	15,947	„	23, „	Whistle.
Maybach,	16,072	„	25, „	Method of producing explosive mixture.
Topping,	16,079	„	25, „	Rotary pumps.
Lewin,	16,290	„	29, „	Adjustable cams.
Spiel and Spiel,	16,410	„	29, „	Combination of vaporiser and cylinder.
Garner and Sherwin,	16,411	„	31, „	Cylinder, two sizes, petroleum engine.

					Speciality.
Drake, . . .	16,575	Sept.	4,	1893,	Vaporiser and ignition tube.
Brünler, . . .	16,752	,,	4,	,,	Measuring commencement of ignition.
Luckhardt, . .	16,821	,,	7,	,,	Improved flywheel brake.
Copley and Atkinson,	16,900	,,	8,	,,	General arrangement, compression space, air and exhaust passages.
Maybach, . . .	16,985	,,	9,	,,	Method of igniting explosive mixture.
Shuttleworth and Shuttleworth, .	17,784	,,	21,	,,	Connecting lamps and vaporiser.
Sherwin, . . .	18,152	,,	27,	,,	Cylinders and pistons, gas and heat engines.
Heatley, . . .	19,373	Oct.	14,	,,	Hot air engine for actuating punkahs.
Ryland, . . .	20,007	,,	24,	,,	Utilising heat from jackets to form steam.
Priestman Bros., .	20,808	Nov.	2,	,,	Improved means of mixing liquids with gases.
Hamilton, . . .	21,120	,,	1,	,,	Compound with side rods.
Brünler, . . .	21,775	,,	15,	,,	Compression with slow combustion.
Barclay, . . .	21,908	,,	16,	,,	Sight-feed lubricators.
Roots, . . .	22,181	,,	20,	,,	Operating valves by gearing.
Pinkney, . . .	22,753	,,	27,	,,	Controlling inlet valves for oil or gas.
Crossley Bros. and Atkinson, . .	23,075	Dec.	1,	,,	Operating exhaust and charging valves.
Strok, . . .	23,175	,,	2,	,,	Outlet valve motion.
M'Donald, . . .	23,660	,,	8,	,,	Valves and pistons for compressing air.
Abel, for Gas Motoren-Fabrik Deutz, .	23,828	,,	11,	,,	Producing elastic fluid.
Durand, . . .	24,258	,,	16,	,,	Propelling power produced by explosion.
Crossley Bros. and Halley, . . .	24,584	,,	21,	,,	Measuring apparatus for supplying and regulating quantity of oil.

Specifications of Patents filed for Gas, Petroleum, and Air Engines for the Year 1894.

Lindemann, . .	263	Jan.	4,	1894,	Compound tandem, impulse at equal intervals.
Abel, for Gas Motoren-Fabrik, . . .	408	,,	8,	,,	Flexible diaphragm, pump controlling valve.
Dulier, ...	573	,,	10,	,,	Generating elastic fluid for working engine.
Lake, for Krupp, .	752	,,	12,	,,	Distribution and ignition.
Campbell, . . .	778	,,	13,	,,	Vaporiser, valves and auxiliary cylinder.
Hill and Brett, . .	1,231	,,	19,	,,	Vaporising and mixing heated air with hydrocarbon.
Bénier, ...	1,581	,,	24,	,,	Engines operated by power gas.

					Specialty.
Foster, . . .	2,064	Jan.	31,	1894,	Double piston.
Thompson and others,	2,065	,,	31,	,,	Auxiliary compressing chamber, valves, and heating air.
Fidler, . . .	2,540	Feb.	6,	,,	Utilising exhaust heat.
Lake, for Grant, .	2,593	,,	6,	,,	Gasoline and hydrocarbon.
Bellamy, . . .	2,656	,,	7,	,,	Ignition and reserve ignition tubes.
Tesla, . . .	2,801	,,	8,	,,	Reciprocating cylinder, piston, and air springs.
Weyland, . . .	3,122	,,	13,	,,	Vaporiser.
Décombe, . . .	3,303	,,	15,	,,	Valves actuated by electro-magnets.
Davy, . . .	3,485	,,	17,	,,	Compressing air and gas into explosion chamber.
Holt, ...	4,301	March	1,	,,	Working valves.
Fiddes and Fiddes, .	4,312	,,	1,	,,	Drawing air through hydrocarbon and charcoal stove for ignition.
Singer, . . .	4,959	,,	9,	,,	Sleeve valves.
Singer, . . .	4,960	,,	9,	,,	Double-acting compression gas engines.
Rollason, . . .	5,218	,,	16,	,,	Governing.
Southall, . . .	5,493	,,	16,	,,	Exhaust valve, vaporiser, gas ignition in oil engines.
Capitaine, . . .	5,577	,,	17,	,,	Isolated vaporiser.
Brünler, . . .	5,680	,,	19,	,,	Igniting petroleum.
Mitchelman, . .	5,681	,,	19,	,,	Combustion cylinder, compression piston, trip gear.
Thompson and others,	5,843	,,	21,	,,	Governor and water jacket.
Hornsby and Edwards,	6,122	,,	24,	,,	Jacketed cylinder and water cooling.
Reid, ...	6,138	,,	24,	,,	Lamp and distribution for ignition.
Adams, . . .	6,364	,,	30,	,,	Rotary reciprocating frame, no crank.
Eaton, . . .	6,647	April	3,	,,	Steam and gas generator engine.
Low, ...	6,755	,,	4,	,,	Closed receiver, regulating compression between two cylinders.
Skene, . . .	7,023	,,	9,	,,	Ejecting and separating burnt products.
Farmer, . . .	7,294	,,	12,	,,	Compression and explosion cylinder.
Schwarz, . . .	7,357	,,	13,	,,	Explosion by chloride of nitrogen.
Merryweather and Jakeman, . . .	7,485	,,	14,	,,	Rotary.
Roots, . . .	7,538	,,	16,	,,	Cylinder cover, ignition tube, and oil-spray nozzle.
Rutter, . . .	7,630	,,	17,	,,	Operating and controlling valves.
Adams, . . .	8,041	,,	24,	,,	Exploding chamber.
Holt, ...	8,295	,,	26,	,,	Diminishing oscillation in gas or oil motor cars.
Clifford and Grove, .	8,663	May	2,	,,	Construction of inlet for air, oil, or gas, and ignition.
Cosalonga, . . .	8,979	,,	5,	,,	Hot air.
Dickenson, . . .	9,305	,,	11,	,,	Double-acting, two impulses per revolution.

					Speciality.
Scott,	9,403	May,	12,	1894,	Oil engine pumps.
Sandermann,	9,723	,,	18,	,,	Steam, gas, and petroleum engine cylinders.
Brünler,	9,788	,,	19,	,,	Formation of mixture according to load.
Haddan, for Pijuet & Co.,	10,034	,,	23,	,,	Turbine driven by explosion.
Holt,	10,113	,,	24,	,,	Reversing, starting, and working in either direction.
Piers,	10,451	,,	29,	,,	Tramcars.
,,	10,452	,,	29,	,,	Obtaining secondary power.
Thompson, for Shoemer,	10,511	,,	30,	,,	Oil motor.
Gibbon,	10,623	June	1,	,,	Combustion chamber, vaporiser.
Schweizer,	10,788	,,	2,	,,	Gas and hydrocarbon
Howard and others,	11,101	,,	7,	,,	Explosive engine.
Davis,	11,108	,,	8,	,,	Self-starting, by head of water or compressed gas.
Lazar and Csonká,	11,119	,,	8,	,,	Mixing chamber.
Hamilton,	11,261	,,	11,	,,	Operating valves, governing, igniting, and heating air.
Wiseman and Holroyd,	11,369	,,	12,	,,	Generating gaseous vapour, starting, driving, igniting, &c.
Redfern,	11,526	,,	13,	,,	Rotary explosive engine.
Haddan, for Paris & Cuvet,	11,593	,,	14,	,,	Pistons and packing.
Lamena,	11,726	,,	16,	,,	Vapour spring for governing.
Dawson,	11,802	,,	18,	,,	Relieving cylinder.
Ganswindt,	11,804	,,	18,	,,	Rotary, reciprocating motion.
Fielding,	11,997	,,	21,	,,	Vaporiser, ignition, and valve gear.
Ewins,	12,520	,,	28,	,,	Pistons.
Tyler and others,	12,820	July	3,	,,	Mixing and burning explosive gases.
Terrey,	12,840	,,	3,	,,	Cooling circulating water.
Boult,	12,917	,,	3,	,,	Reversing gear.
Griffin,	13,298	,,	10,	,,	Double piston (twin).
Marks, for Hirsch,	13,333	,,	10,	,,	Gas, &c., engine.
Vermersch,	13,524	,,	12,	,,	Inspection of engine, regulating, igniting, and starting.
Burt,	13,546	,,	13,	,,	Controlling gas or oil road motor cars.
Arschauloff,	13,825	,,	18,	,,	Double cylinder caloric engine.
Holt,	14,002	,,	20,	,,	Driving gear for gas motor cars.
Bryant,	14,476	,,	27,	,,	Gas engine.
Schumacher,	15,061	Aug.	7,	,,	Rotary perforated valves and seating.
Schimming,	15,109	,,	7,	,,	Explosion motors, injecting water and steam.
Fauve,	15,152	,,	8,	,,	Petroleum motor with air carburator.
Weyman,	15,272	,,	10,	,,	Vaporiser and water jacketed cylinder.
Bagshaw,	15,435	,,	14,	,,	Springs for packing and expanding piston rings.

					Speciality.
Priestman Bros.,	15,721	Aug.	17,	1894,	Heating vapour chamber, starting.
Hall,	15,866	,,	21,	,,	Improved governor for compressed air engine.
Rigg,	15,888	,,	21,	,,	Improvements in engines.
Saurer-Hauser,	16,230	,,	25,	,,	Heating mixture of air and gas, and igniting.
Scherfenberg,	16,688	Sept.	1,	,,	Improved oil engine.
Eisenbus,	16,984	,,	6,	,,	Fan and compressed air motor.
Knight,	17,233	,,	11,	,,	Utilising waste heat of lamp.
Roots,	17,308	,,	11,	,,	Internal combustion cylinder, closed.
Maccallum,	17,549	,,	15,	,,	Internal combustion, for liquid and powdered fuel.
Bedson and Hamilton,	18,452	,,	29,	,,	Treating exhaust gases and vapours.
Shillito,	20,123	Oct.	22,	,,	Two pistons in one cylinder.
Grove and another,	20,192	,,	23,	,,	Operating valves and admission of oil and air.
Norris and Henty,	20,538	,,	26,	,,	Air engine.
Aulit,	20,969	Nov.	1,	,,	Air and petroleum motor combined.
Abel,	21,829	,,	12,	,,	Working method, slow combustion.
Armstrong,	22,852	,,	26,	,,	Hand starting gear.
Turner,	22,891	,,	26,	,,	Starting handle for gas or oil motors.
Clark and Lanchester,	22,946	,,	27,	,,	Compound gas and similar engines.
Robinson,	23,028	,,	27,	,,	Tandem gas and vapour engine.
Pollock and Whyte,	23,802	Dec.	...	,,	Oil engine.
Marks,	24,089	,,	11,	,,	Double cylinder.
Heys,	24,133	,,	12,	,,	Operating valves.
Withers,	24,239	,,	13,	,,	Gas engine.
Hawkins,	24,898	,,	21,	,,	Explosive mixture for motive power.
Lake,	25,140	,,	27,	,,	Noiseless exhaust.
Cordingley,	25,275	,,	29,	,,	Ignition.

Specifications of Patents filed for Gas, Petroleum, and Air Engines for 1895.

Humphrey,	347	Jan.	5,	1895,	Gas or oil motor, general.
Niemczik,	546	,,	9,	,,	Generation of gas and ignition.
Pinkney,	644	,,	10,	,,	Reservoir for compressed charge of gas and air.
Karavodin,	749	,,	11,	,,	Fluid pressure heat engine, general.
Marks,	946	,,	15,	,,	Opposed power cylinders.
Wane and Horsey,	973	,,	15,	,,	Internal combustion engine, general.
Lones,	1,046	,,	16,	,,	Operating air and gas valves.
Boult,	1,071	,,	16,	,,	Cylinder liner for expansion and contraction.

					Speciality.
Karavodin, . . .	1,090	Jan.	16,	1895,	Generator for heated combustion gases.
Halling and Lindahl, .	1,310	,,	19,	,,	Operating valves.
Millet, ...	1,580	,,	23,	,,	Petroleum velocipede.
Niemczik, ...	1,922	,,	28,	,,	Starting gas and petroleum engines.
Clarke, ...	2,327	Feb.	2,	,,	Valve motion.
Crastin, ...	2,550	,,	5,	,,	Water jacket and operating valves.
James, ...	2,638	,,	6,	,,	Extraction of foul gases.
Clerk, ...	2,890	,,	9,	,,	Pneumatic pressure hammer.
Stanley, ...	3,357	,,	15,	,,	Segmental cylinders and connecting-rods.
Labinal, ...	3,490	,,	18,	,,	Rarifying or compressing gases.
Crossley, ...	3,638	,,	20,	,,	Oil pump and lamp for oil engines.
Warner and Rockham,	3,783	,,	21,	,,	Internal combustion engine, general.
Collis, ...	3,806	,,	22,	,,	Oil, gas, or vapour, general.
Wallman, ...	3,923	,,	23,	,,	Regenerator and heating walls of cylinder.
Binns and Binns, .	4,116	,,	26,	,,	Expelling exploded gases and admitting oil to vaporiser.
Diesel, ...	4,243	,,	27,	,,	Regulating fuel supply and mixture of fuel.
Furneaux and Butler,	4,604	March	4,	,,	Starting, combination of pump and inspirator.
Tangye, Limited, and Robson, ...	4,786	,,	6,	,,	Two-power cylinders, side by side, or end to end.
Kolbe, ...	4,972	,,	8,	,,	Arrangement of reciprocating and oscillating parts.
Johnson, ...	5,373	,,	14,	,,	Motor vehicle.
Wildt, ...	6,151	,,	25,	,,	Improved gas engine.
Southall, ...	6,383	,,	28,	,,	Baffle in cylinder and operating valves.
Brayton Petroleum Motor Co. and Townsend,	6,523	,,	29,	,,	Governing.
Merichenski and Moffat,	8,120	April	24,	,,	Production of gas from oil for heating and motive power.
Klunzinger, . . .	8,355	,,	27,	,,	Ignition for gas or oil engines.
Redfern, ...	8,982	May	6,	,,	Air engine, general.
Berrenberg, . . .	9,922	,,	20,	,,	Wheel motor for cycles.
Mex, ...	9,964	,,	20,	,,	Double-acting petroleum motor.
Bell and Clerk, . .	10,710	,,	30,	,,	Heating air and oil previous to vaporising.
Duryea, . . .	11,400	June	11,	,,	Motor vehicle.
Green, . . .	11,493	,,	12,	,,	Self-starting gear.
Holt, ...	12,095	,,	21,	,,	Operating valves.
Diesel, . . .	12,306	,,	25,	,,	Heating and cooling the air.
Macdonald, . . .	12,409	,,	26,	,,	Heating and cooling cylinders for tramcars.
Lorenz, . . .	13,675	July	17,	,,	Vertical petroleum motor, general.

					Speciality.
Spiel, ...	13,975	July	23,	1895,	Combined vaporiser and ignition.
Spiel, ...	14,009	,,	23,	,,	Ignition and vaporising.
Lorenz, . . .	14,361	,,	29,	,,	Hydrocarbon engine, general.
Durr, ...	14,385	,,	29,	,,	Operating valves.
Hinchliffe, . . .	15,411	Aug.	16,	,,	Vaporiser.
Grist, . . .	16,096	,,	27,	,,	Vaporiser and mixing the vapour with air.
Weatherhogg, . .	16,703	Sept.	6,	,,	Ignition and vaporising.
White and Middleton,	16,891	,,	10,	,,	Gas engine, special, general.
Hoyle, . . .	17,560	,,	15,	,,	Furnace gas or heat motor.
Brünler, . . .	19,568	,,	18,	,,	Operating valves.
Kane, . . .	20,305	,,	28,	,,	Mixing and volatilising gases and ignition.
Enger, . . .	21,484	Nov.	12,	,,	Governing and regulating by electricity.
Green, . . .	21,594	,,	14,	,,	Self-starting arrangement.
Wise, ...	23,113	Dec.	3,	,,	Water-jacketed cylinder.

SECTION E.

SUMMARY OF EXPERIMENTS ON A TWIN-CYLINDER OTTO GAS ENGINE.

BY DR. A. SLABY.

Object.—These valuable experiments were made by Dr. A. Slaby, Professor at the Technische Hoch-Schule, Berlin, to investigate the heat cycle in a gas engine. The object with which they were undertaken was, in Dr. Slaby's words, to "determine by measurements the division of heat in a gas engine, in order to deduce therefrom the conditions for the best utilisation of the combustible." They have been published from 1890 to 1892 in six pamphlets, comprising 196 pages, illustrated by many plates and diagrams, and form the most exhaustive treatise on this particular subject with which the author is acquainted. An abstract of their contents is here given, and will, it is hoped, serve as an introduction to that careful study of the original, which Dr. Slaby's laborious researches merit.

The engine experimented on was a twin-cylinder horizontal 8 H.P. German Otto engine, employed for driving the electrical laboratory in the Berlin Technical High School. The gas used was always lighting gas, made from Upper Silesian coal, from the gas-works at Charlottenburg, near Berlin. The diameter of the cylinder was 172·5 mm. = 6·8 inches, and stroke 340 mm. = 13·3 inches. In all, 306 experiments were made, from 1886 to 1890, divided into two sets, but Dr. Slaby is still continuing his work on the same engine. For further details of the motor see p. 466.

Heating Value of the Gas.—Pamphlet I.—The author begins by expressing his desire to elucidate the various questions still undecided in the theory and practice of the gas engine. With this object it is necessary, he considers, first to determine the composition and heating value of the gas used. The chemical constituents of any gas depend upon the raw material (coal), the process of generation and purification, and time which has elapsed since the beginning of distillation. But the difficulty of arriving at an exact knowledge of the heating value and composition of any given gas is

so great as to be almost insuperable. The subject has never been thoroughly investigated. All that can be done, to ensure uniformity in the constituents of lighting gas during a test, is to carry out the experiments always at the same hour of the day, with gas from the same main.

Not only is the composition of gas given differently by different authorities, but the proportions of heavy hydrocarbons are variously estimated. Some writers class them all as C_4H_8, some as C_2H_4, some as half one, half the other, producing a difference in the heating value of the gas of 8 per cent. This method was not sufficiently accurate for the author's purpose. After many trials he found that the heat value of each hydrocarbon could be expressed as

$$H = 1{,}000 + 10{,}500 \times \text{ the density of the hydrocarbon}$$

(H representing the heating value in calories per cubic metre), and that this formula was also applicable to any given mixture of the same. It was necessary, therefore, to determine the density of each gas to within ¼ per cent., instead of taking the residuum in the gaseous mixture, after analysing the different constituents H, CH_4, CO, &c., as nitrogen, and reckoning its weight as such.

To calculate the density of the hydrocarbons, a Schilling apparatus was used, of which a drawing and detailed description are given in the original. By this instrument it was found that the densities of any two gases were inversely proportioned to the squares of their speed of discharge, at the same pressure, through a narrow orifice. The experiment being carried out first with air, then with gas, the density of the latter was thus determined. Great care was taken to ensure an even temperature. Satisfactory results were obtained by these means, but it was necessary to check them by experimenting upon perfectly dry lighting gas; the Schilling apparatus being immersed in water, the gas in it was always slightly damp. The difference between moist and dry gas was considerable. *Saturated air weighed* 0·75 *per cent. lighter than dry air, but saturated gas weighed* 0·94 *per cent. heavier than dry gas.* The gas was next directly weighed. Two glass vessels were filled respectively with dry gas and dry air, and after being both brought to the same temperature and pressure, they were weighed. Immediately after, the glass vessels were weighed alone, and the proportional weights of the gas and air thus determined. The correction for the Schilling apparatus was found to be only 0·07 per cent., but this accuracy was obtained after years of practice, comprising about 1,000 determinations. Finally the Lux gas weigher was used, and gave excellent results, about 3·8 per cent. higher than the Schilling, owing to the dryness of the air and gas, and faults in calibrating.

To determine the heat value of lighting gas, the percentage in volume of the heavy hydrocarbons was ascertained by analysis. The specific weight of the gas being known, and the residuum taken as pure nitrogen, the specific weight of the heavy hydrocarbons was deduced from the weight of the gas with and without them. This method has the disadvantage of assuming that the residuum consists entirely of pure nitrogen, whereas it is known to contain ammonia and other substances. A more satisfactory process was as follows:—The gas was first carefully weighed, then passed through tubes and vessels containing glass shavings, sulphuric acid, potash, water, &c., to separate the hydrocarbons and carbonic acid. The purified gas was then again weighed, and the density of the heavy hydrocarbons found by deduction to be a mean of 1·72. This agreed well with the ordinary analysis of Berlin gas. It may therefore be assumed that in any given gas the mixture of heavy hydrocarbons is essentially a constant, the greatest difference in the heat value being 8 per cent. During one day of a trial, the difference was seldom more than 1 per cent. It is necessary, however, in making an experiment, to determine the heat value of the mixture of

heavy hydrocarbons, which vary from 13,000 to 27,000 calories per cubic metre. Throughout the experiments it was taken at 19,000 calories per cubic metre.

Products of Combustion.—In the Second Pamphlet the composition of the products of combustion is considered, and the constants determined. The specific weight of 1 cubic metre is 0·417, with a heating value of 4,883 calories. For complete combustion the weight of oxygen required for 1 cubic metre of lighting gas is 1·515 kilo., and of air 6·425 kilos. or 4·965 cubic metres. The combustion produces 6·965 kilos. or 5·684 cubic metres of products, or a contraction of 4·8 per cent. Analyses of the products of combustion with different dilutions of air were carried out on seven different days, and the mean taken. In none of them could any trace of unburnt hydrocarbons or carbonic oxide be discovered. These analyses do not give the percentage of steam, which is certainly superheated, and is reckoned, for the above proportions, at 1·209 cubic metre. The different constants for proportions of 5, 6, 7, and 8 volumes of air to one of gas are shown in a table and plotted out, namely—Percentage of contraction during combustion; weight and specific weight of 1 cubic metre of the mixture before combustion, and of 1 cubic metre of products; and constants of the products.

The next question to determine was the specific heat of the products of combustion. The author distinguishes between true and mean specific heat; the former increases twice as much for a given increase of temperature as the latter. The increase in true specific heat per degree rise in temperature, for the gas composing the products of combustion in a gas engine, is given from Mallard and Le Chatelier, and the values calculated at constant pressure, and at temperatures of 0°, 100°, 500°, 1,000°, 2,000° C. From these the specific heats, at constant pressure, of the products of combustion under the same conditions are reckoned, and plotted out. The horizontal lines show the rise in temperature of the gases from 0° to 2,000°, the verticals the increase in their specific heat at constant pressure, for a given dilution of gas and air.

Engine and Instruments.—The experiments to verify these calculations were carried out on the engine already described (drawings of which are given). The quantities of gas, air, and of cooling water were carefully measured. During the experiment only one cylinder was used, the other being employed to determine the piston friction. The quantity of gas was measured by a glycerine gas meter, marked to show half litres, the consumption for the ignition flame being given by a separate meter. Both meters were carefully tested before the experiments, and thermometers inserted in them, from which the temperatures could be read off. From the meters the gas passed to the engine through rubber bags, a pressure gauge being fixed in the admission passage. In all the experiments the air was measured in a gas meter, provided with a scale, thermometers, and pressure gauge. The error in this meter was found to be under ½ per cent. The air was forced into the air meter by means of a small fan, driven by a little water motor. The pressure was determined by passing it, before it entered the meter, through a small air holder, maintained by weights at a constant height. The cooling jacket water passed to the engine through pipes in which small copper tubes were inserted, one at the entrance, the other at the exit; these tubes contained delicately graduated thermometers. The quantity of water was previously measured in gauged tanks, and afterwards passed into another tank.

The governor was not acting during the experiments. The opening admitting the gas could be adjusted by means of a screw, but in the trial the mixture was kept uniform, with the same proportion of gas. Speed counters were arranged on the crank shaft and valves.

Temperature of Gases at Exhaust.—The next question was to determine the temperature of the gases of combustion. The author began by

taking the temperature with pyrometers fixed in the exhaust passage, but found an error of 50° in the best instruments. He next operated with ordinary glass, quicksilver, and nitrogen thermometers, marking up to 460° C. By cooling the cylinder very considerably, and greatly reducing the speed, it was possible to reduce the temperature of the exhaust gases to the desired limit. No practical results were, however, obtained until a ball calorimeter was used. In the ordinary exhaust pipe a cock was fixed which, when open, allowed the gases to pass in the usual way into the atmosphere. When closed, the gases of combustion were forced through another channel, joining the main exhaust pipe at a point below the cock. In this pipe was a hollow cock, the socket of which contained an iron ball. By turning the cock 90° either way the ball could be introduced into the socket, or allowed to fall out below. To make an experiment, the gases were first shut off from their usual course, and the side cock opened, causing them to flow through an auxiliary pipe. The ball being previously placed in the socket, and kept in position by wire-netting, it was exposed for half an hour to the current of the hot exhaust gases. A calorimeter containing water was then placed beneath it, the cock turned, and the ball dropped into the calorimeter, when its temperature was determined in the usual way by the rise in temperature of the water. The author thus succeeded in obtaining accurately the temperatures of the exhaust gases which, plotted on a curve, were compared with those arrived at with an ordinary thermometer.

The indicators employed were of various kinds. No brake was used on the engine during the experiments, because the author, who worked for the most part entirely without help, was not able to carry out brake at the same time as calorimetric experiments. The brake efficiency was at other times carefully noted.

Volume of Clearance Space.—The compression or clearance space of the engine was 60 per cent. of the total suction volume of the piston. This was determined—1, By direct measurement of the internal dimensions of the cylinder; 2, by filling the cylinder with water, and thus measuring both the compression space and volume engendered by piston.

Piston Friction.—The piston friction was next calculated, the heat thereby generated affecting materially the heat balance of the motor. This was done by shutting off one of the two cylinders, and running it without gas; the rise in temperature of the jacket water gave the heat due to the piston friction. Seven experiments were made on two different days, and 50 litres of circulating water used. The trial varied from half an hour to an hour and a half, and the rise in the temperature of the water, corrected for the heat of the room (which was always about 3° higher than that of the water at discharge), varied from 5° to 8°. The number of calories carried off per cycle varied from 0·09 to 0·13. The mean temperature of the walls was about 3° below that of the water at discharge.* The results, when plotted out, showed that the friction of the piston decreased with the rise in temperature of the walls for about the same number of revolutions; in other words, the higher the temperature of the walls, the less heat was carried off by the jacket water, or the less friction was generated. This was clearly revealed by the experiment of the 21st April, 1888, and the piston friction was found to depend not on the speed, but on the mean temperature of the walls. Thus with a mean wall temperature of 9°·4, the heat generated by the piston during two revolutions, or one cycle, was 0·183 calorie; with a wall temperature of 15°·6 it was 0·17 calorie. The speeds varied from 97 to 182 revolutions per minute. These results are worked out and summed up in a table, showing the generation of heat by piston friction, with a wall temperature of 10° to 55°. Taking into account the indicated work, the author arrived at the conclusion that, *the lower the*

* The temperature of the cast-iron cylinder wall was always taken as a mean between the temperature of inlet and outlet of jacket water.

wall temperature the greater the friction. With a temperature of 10°, nearly one-third the indicated work was expended in piston friction; it sank to 6·5 per cent., with a wall temperature of 40°, corresponding to a temperature of the water at discharge of 70°. If it were possible to reduce the wall temperature to 3°, the engine would not be able to overcome the frictional resistance.

General Cycle.—Pamphlet III.—The amount of heat turned into indicated work during a complete cycle in a gas engine, is influenced by the following factors:—1, Heat value of the gas; 2, piston speed; 3, temperature of the walls; 4, proportion in which the gas is diluted with air, or with neutral gases; 5, amount of compression before ignition. To study a gas engine properly, each of these five should be separately varied, the others being maintained constant. The heat value of the gas having been already considered, the next question is the influence of the piston speed. The author found that his experiments did not confirm the general opinion that the efficiency increased with the speed. The gas consumption per I.H.P. per hour, when the engine was running at 87 and at 180 revolutions per minute, was practically the same, the temperature of the out jacket water varied only 2° or 3°. The I.H.P. was more than one-third higher at the above high speed, but the negative work was greatly increased. "As these results were questioned," says the author, "I repeated my experiments in sets of two together on the same day, and proved that, if a motor is allowed to run continuously for some time, and the speed be increased, certain phenomena intimately connected with it make their appearance, which not only counterbalance the favourable effect of the augmented speed, but act prejudicially in the opposite direction. These influences are principally manifested by the rise in temperature of the products of combustion, and the increase of the negative work, corresponding to the periods of exhaust and admission in the gas engine. The increase in negative work was revealed by the indicator which, with a weak spring, showed that the mean pressure corresponding to the negative work rose from 0·070 kilo. per square centimetre when the engine was running at 92 revolutions, to 0·242 kilo. per square centimetre at 191 revolutions. The temperature at which the products were discharged rose at the same time more than 150°."

Two series of experiments were undertaken to determine the influence of the speed, and yielded results at variance with those obtained by Professor Witz. The temperatures of the jacket water and exhaust gases were measured as described.

The cycle of the gas engine was divided into—1, Admission; 2, Compression; 3, Ignition; 4, Expansion; 5, Discharge, and each of these periods was studied experimentally.

Considering first the admission period, the author found that though the proportion of air to gas varied a little, the mean temperature of the jacket water, or that of the walls, rose slightly, though not in every case, and the temperature of the exhaust gases always, in almost exact proportion to the increase in the speed. With 90 revolutions the exhaust temperature was 400° C., and with 170 revolutions, 529° C. The total volume of the charge drawn in per stroke decreased with increase of speed; with double the revolutions it fell more than 20 per cent. This proportion varied in the different experiments, the difference being less, the higher the speed. It was clearly a result of the available admission volume, which was dependent on the pressures at beginning and end of the cycle, and upon the mean temperatures at these two periods. To determine the pressure during admission, it was necessary to know how far the line of admission varied in pressure from that of the atmosphere. This initial pressure was found to increase in almost exact ratio to the increase of speed, from whence the author concluded that it *depended entirely upon the number of revolutions.*

Other experiments on the back pressure of the exhaust gases showed that, at the moment the exhaust valve closed, the pressure line rose

slightly, in fairly exact proportion to the number of revolutions. It was always higher with increase of speed, varying from 8 mm. with 98 revolutions, to 14 mm. with 184 revolutions (scale—29 mm. = 1 kilo. per sq. cm.) Plotting out the values obtained, the author found that, however the conditions of discharge were varied, the pressures always rose with the increase of speed, but much more gradually after the engine had been running for an hour, and a certain equilibrium in working was obtained. Thus the exhaust as well as the initial pressure depended entirely on the speed.

The temperatures at admission and discharge of the gases remained to be considered. The first the author had no means of determining. The temperature of the products of combustion left in the cylinder is about the same as that determined with the calorimeter and ball, but at the moment the exhaust valve opens, the author verified a sudden momentary rise of 2° or 3°. Nevertheless he assumed that the mean temperature of the products in the cylinder, and of the exhaust gases, was the same. The temperature of the exhaust gases was higher in the one set of experiments than in the other, about 3 per cent. absolute temperature at 150 revolutions, although the speed and the volume of the charge were the same, and this was explained by the difference in pressure, which was 14 per cent. By itself this difference should have produced a higher exhaust temperature; but the mean temperature of the walls was on the other hand 5° lower, thus showing their influence on the temperature of the exhaust. The temperature of the charge in the cylinder at the end of admission was obtained by calculation. Plotted out on curves, the figures showed that this temperature also increased with the speed, but not much. With double the number of revolutions, the increase was only from 106° C. to 128° C. The two experiments showed the same variation of temperature as before verified, about 7° at equal speeds (150 revolutions). Hence the mean temperature of the products left in the cylinder had but a slight influence upon the mean temperature of the freshly admitted charge. The author was able to determine with certainty that the temperature of the charge at admission was about 100° higher than that of the cooling water at discharge.

He sums up these researches by stating that the differences in the volume of the charge can be explained only by these differences of pressures and temperatures, which he formulates thus—

$$\frac{\text{pressure at admission of charge}}{\text{abs. temperature at admission of charge}} = 31 - 0{\cdot}049 \times \text{number of revs.},$$

$$\frac{\text{pressure at exhaust}}{\text{abs. temperature at exhaust}} = 22{\cdot}64 - 0{\cdot}0238 \times \text{number of revolutions.}$$

These were the values for the first set of experiments. They differed in the second experiments chiefly in respect to the exhaust temperature and pressure, which, unlike the admission pressure and temperature, *depended on the mean wall temperature as well as the speed.*

Walls during Admission—Speed Effect.—The author next endeavoured to determine the action of the walls during admission, their temperature being then lower than that of the gases in the cylinder. The difference between the heat given off by the products in the cylinder, and that absorbed by the fresh charge passes into the cooling water, and it is necessary to know the weights of the products, of the gas, and of the air composing the charge. The weight of the products he found to diminish in *exact* ratio to the increase of speed, being with 90 revolutions 3·21 grammes, with 184 revolutions 2·88 grammes. The specific heat of the products increases. On the other hand, the heat carried off to the cooling water during admission increases greatly with the speed. In the first set of experiments it rose from 0·08 cal. to 0·16 cal., the speed being doubled, and in the second from

0·02 cal. to 0·10 cal. for the same increase of speed, the temperature of the walls in the latter case being about 5° higher. "It follows," says Dr. Slaby, "that for the heat given off to the walls the rise in temperature of the products, increasing with the speed, has a far greater effect than the diminished time of contact with the walls."

Hence he deduces that the pressures and temperatures at admission and exhaust are variable, and depend on the speed, and the mean temperature of the walls. The admission pressure and temperature depend on the speed, and are but slightly affected by the temperature of the products with which the fresh charge mingles, and that of the cooling water. The exhaust temperature and pressure are greatly affected by the walls. If no water is allowed to collect in the exhaust pipe, the pressure of exhaust becomes a function of the speed, and the proportion of pressure to temperature of exhaust, the wall temperature and dilution of the charge being maintained constant, can be approximately calculated from the speed. Thus formulæ are obtained for calculating the volume of the charge admitted per stroke, the total weight (including that of the products) and quantity of heat given to the cooling jacket. The author considers that the greater the number of revolutions the smaller the charge, and he says further:— "If the quantity of gas admitted is smaller at high than at low speeds, it will be evident that the difference between the heat given off by the products during admission, and the heat taken up by the freshly admitted charge must be considerably increased by increase of speed."

Indicators.—Pamphlet IV.—The least known part of the gas engine cycle is that comprising the ignition and expansion of the charge. There is only one way of determining the connection between the spread of the flame and the cooling influence of the walls, namely, an analysis of the indicator diagram. The author, therefore, devotes the whole of this pamphlet to an exhaustive study of indicators (Crosby and others) and a determination of their limits of error. The indicators chiefly used during the experiments were a Crosby and a Storchschnabel.

Compression.—Pamphlet V. deals with compression in the gas engine. During this period the amount of heat set in motion and its direction should be determined. The problem is simple, if the compression curve be replaced by a "polytropic" * curve.

$$p\,v^m = \text{const.}$$

The initial pressure having been shown to depend entirely on the speed, the compression pressures must be taken from the diagrams. The mean pressures for two sets of experiments are given in tables, and when plotted out, the abscissæ representing the number of revolutions, and the ordinates the pressures of compression in millimetres above atmosphere, these compression pressures are shown to follow a strict law, and to decrease in proportion to the increase of the speed. This law the author reduces to a formula. From the two sets of experiments he lays down the proposition that *the compression pressure depends entirely upon the speed of the engine, and can be reckoned by a given formula.* Desiring next to know if the compression curve agreed with the polytropic during its whole course, he calculates the pressures, at half way through the stroke, from all the diagrams of the second set of experiments. They were also found to diminish with increase of speed, though not to the same extent as the initial pressures, and thus the compression curve agreed with the polytropic throughout its course, and could be accurately calculated, the exponent being 1·29. To prove its variation from the adiabatic, the author reckoned the specific heat for both curves at

* "Polytropic" is the name given by Zeuner to any curve which can be represented by the formula $p\,v^m$ = constant. The isothermal and adiabatic curves come under this law, with different exponents, m; the polytropic may be called the generic curve, of which the isothermal and adiabatic are varying forms. For a full explanation of the law, see Zeuner, *Thermodynamik*, and Schöttler.

constant pressure and volume of the mixture of gas, air, and products. It was considerably higher for the adiabatic than for the polytropic curve, with which he had proved the compression curve to agree, and hence he concludes that *during compression there is a loss of heat to the walls.* Other conditions being equal, this compression pressure is a function of the speed. Thus at 100 revolutions, the initial pressure being atmospheric, the pressure of compression is 3·50 kilos. per square centimetre; at 200 revolutions (double speed) it is 3·06 kilos.

The mean temperature during compression increases with the speed. With a mean temperature of 200° C. the specific heat of the products of combustion is 11·5 per cent. higher than at 0°. The mean rise is 130°, the proportion between the initial and compression temperatures remaining constant at 1·32. The work of compression, especially the increase in the internal work, also depends upon the speed. The change of condition is accompanied by a carrying off of the heat, but this abstraction of heat is small, and slightly diminishes with increase of speed.

Ignition Period.—The next question considered is the ignition period. This can only be studied by the help of the indicator diagrams taken by the author in each experiment. The differences in the diagrams obtained under precisely similar conditions the author attributes to the varying composition of the gas mixture which, even if the valve action is perfectly regular, is subject to uncontrollable fluctuations, due to slight differences in the speed of ignition. It is well known from Mallard and Le Chatelier's experiments that the speed of ignition increases up to a maximum with increasing richness in the gas mixture, but if the proportion of gas be still greater, it falls again. The indicator diagrams showing the effect of a richer or poorer mixture give curves sinking regularly one below the other with the decrease in the proportion of gas in the mixture, but do not explain the variation in the rounding shape of the top of the diagram. The author does not attribute this to the ignition flame, but considers that it is probably caused by differences in the local arrangement of the charge, and not by fluctuations in the strength of the mixture, which can hardly occur when the engine is running regularly. The small, perfectly vertical part of the indicator diagrams obtained by him is due to the force of the explosion in the ignition port; the rest of the line, deviating more or less from the perpendicular, represents the ignition of the remainder of the charge. At the top of all diagrams (taken with double springs) he found a distinct "nick," marking the point where expansion and fall of pressure began. To this, the point of highest temperature in the cycle, he devoted careful study.

Considering first the temperature and pressure of compression, and of this maximum point in the diagram, he reckons the mean specific heat of the charge at constant volume from that at these two points. The amount of heat shown by the diagrams in the area enclosed between the point of highest compression and of maximum temperature (ignition), the atmospheric line and the corresponding ordinate of pressure, is always less than that set free by the combustion of the gases. This difference in heat must be accounted for in one of three ways. Either it is developed during this period, in which case it must be entirely absorbed by the walls; or incomplete combustion, "nachbrennen" takes place; or both processes are combined. Analyses of the products prove that, at some period of the stroke, there is perfect combustion of the whole gaseous mixture. If the heat passes into the walls, the amount thus transferred must be in proportion to the surfaces in contact, time of exposure, and difference of temperature. If "nachbrennen" is produced, it must depend on the proportional composition of the charge, and on the speed, and be increased by poorer mixtures and greater speeds. The figures obtained by the author show, especially with reference to the speed, that this is *not* so. Taking the difference between the total heat of the charge at this point of the stroke, and the heat of combustion shown in the diagrams, and plotting them out, the

author finds the percentage of this difference to be higher with low than with greater speeds, being 8·5 per cent. with 179 revolutions, and 13·2 per cent. with 100·6 revolutions. At 150 revolutions about 10 per cent. of the total heat disappeared. As neither the surfaces nor the maximum temperatures vary much, the differences producing this loss of heat must lie in the time of wall contact. If all this heat passes into the walls, it will be proportioned to the time the indicator pencil takes to travel from the compression to the ignition point, or what the author calls the "time of ignition." The phenomenon cannot be caused by irregularities in the action of the engine, because these, when tested for time with the usual tuning-fork apparatus, were found to be less than ½ per cent.; the speed was therefore constant.

The author proceeds to find the angle through which the crank passes during this period, and expresses in a formula the proportion between the distance passed through, and the angle of crank revolution. By these means he was able to determine the time occupied in traversing the distance, in proportion to the speed, which, when plotted out, showed that the shorter the time the less heat disappeared. The increase in the heat lost was proportioned to the duration of combustion. Hence the author assumes that, *at the point of highest temperature combustion is ended, and the heat not shown in the diagrams has wholly passed into the walls.*

Speed of Ignition.—Having thus arrived at the time of ignition, the author was able to determine approximately the speed of ignition. By calculation and measuring the diagram, he reckoned the total length of the ignition channel in proportion to the length of stroke, and was thus able to express the ignition speed in a formula. This speed of ignition was nearly doubled with twice the number of revolutions, being for 100 revolutions 2·6 metres per second, and for 180 revolutions 4·5 metres. These figures agree with Mallard and Le Chatelier, who found that the speed of ignition increased greatly when the gas was in a state of violent motion, and attributed the phenomenon not only to conduction, but to differences of speed in the component parts of the gas. As the charge in a gas engine must be in violent motion during ignition, combustion is really complete at the point of maximum temperature, between ignition and expansion. Thus there is a sudden explosion and rise in pressure at first, then a powerful flame darts into the cylinder, and with a smaller speed of propagation ignites the whole charge. This speed of propagation is affected by—Composition of the mixture; speed of the engine (shown in the more rapid motion produced in the cylinder); the particular local stratification of the gaseous mass, whether homogeneous or otherwise. Combustion is completely ended in from 0·03 to 0·06 second, corresponding to the maximum mean temperature, after which expansion, without addition of heat, takes place. No dissociation is possible, since the maximum temperature is never above 1,600° C. During combustion the flame certainly comes in contact with the walls, and transfers to them some of its heat. But this is only from 8 to 13 per cent. of the total heat, and therefore, considering the difference between the heat conductivity of the metal and that of the products of combustion, we may conclude that this contact does not last long. The process of combustion chiefly takes place in the kernel of the charge, surrounded by neutral gases. The author therefore is of Otto's opinion, and considers that the composition of the centre of the charge not being homogeneous, a more favourable economic effect is produced.

Expansion Period.—Pamphlet VI. treats of the period of expansion. The author calculates the heat lost to the walls during this period from the difference between the area of work in the diagram, and the total heat of the gaseous mass. The expansion curve he divides into sections, and traces polytropic curves from one ordinate of pressure to the next. The exponent, already given, is governed by the speed. The values thus obtained are plotted out, and when compared with true adiabatic curves, the author

found that during expansion *there is a continuous carrying off of a large amount of heat to the walls, the temperature falling at first, and then rising.* This is explained by the combined influence of the decreasing temperature and increasing wall surface exposed. At the beginning of expansion, the quantity of heat carried off is determined by the temperature, at the end of expansion, by the cooling wall surface. It is only at a speed of 400 revolutions per minute that the expansion curve approximates to the adiabatic.

Considering next the fact, shown already to be probable, that during expansion no increase of heat is produced by internal heating, the heat parted with externally must be at the expense of the internal energy of the gas. This can be calculated from the temperatures and the corresponding specific heats at constant volume. The difference between this internal energy and the external work done shows the amount of heat imparted to the walls. These three quantities can be expressed either as heat or as work. As work they may be measured on the indicator diagram as functions of the lengths of stroke, and represent the divisions of heat. The two quantities of internal and external heat are reckoned for any given portion of the stroke, converted into units of work, and divided by the volume passed through by the piston. Plotted out, they show that the abstraction of heat by the walls follows a regular course. At first the walls are relatively very cool, and the temperature of explosion very high. As the wall temperature rises, less heat is abstracted, and at the end of combustion a minimum is reached. The heat curve now rises, because the cooling surfaces are increased by the out stroke, but about the middle of the stroke another fall is produced by the increased piston speed. It again rises at the end of the stroke, as the speed is reduced. These curves show only the amount of heat actually abstracted, and do not enable us to verify the progress of combustion, and whether part of the heat carried off is developed by "nachbrennen." They reveal, however, that the heat parted with to the jacket during expansion, is inversely as the speed. The higher the speed, the less heat is carried off.

Exhaust Period.—This may be divided into two parts. During the first, occupying the last tenth of the forward stroke, a portion of the gases escape, carrying off part of the total energy of the charge, in the shape of "*force vive*," or "energy of exhaust" (as Zeuner calls it). The remainder of the gases are discharged at lower speed during the return stroke. The author endeavours to determine the heat value of this "energy of exhaust" from the heat balance of the engine. The heat received is the heat set free by the combustion of the lighting gas. The heat going out is divided into—1, Indicated work, both positive and negative, measured from the area of the diagrams, and reduced to calories. 2, Heat passing into the walls and carried off into the cooling water, less the heat absorbed in piston friction. The latter heat value is calculated, as before stated, from the rise in temperature of the jacket water and the quantity used, which was always 200 litres; the time of passing this quantity through the jacket varied from fourteen to twenty minutes. 3, The appreciable heat carried off in the products of combustion. The weight of the products is known, being the same as the weight of gas and air admitted per stroke. Their mean temperature is calculated from the weight of the gas and air, plus their specific heat at constant pressure, and the difference between the temperatures at admission and exhaust. The values obtained are shown in a table. 4, Heat value of the work of resistance during exhaust. This is reckoned from the difference in volume, namely, the increase during the time from the opening of the exhaust valve to the end of the stroke (about one-tenth of stroke), and is distinct from the heat value of the return or exhaust stroke. 5, The "energy of exhaust," or the momentum of the products at the beginning of exhaust, shown by the difference between the pressure at the opening of the

exhaust valve and the constant back pressure during the return exhaust stroke. This difference is plotted on a curve.

The variations shown are referred by the author to the accumulated action of the walls. Time is necessary, that the metal may reach a state of thermal equilibrium. At the beginning of an experiment the walls are still affected by the preceding trial, and contain more or less heat, according to the previous speed of the engine. In this way the author determines the heat accumulated in the walls, that taken up by them, but not carried off in the cooling jacket, and that withdrawn from the walls, but not from the cycle. The values obtained for this "energy of exhaust" give the mean speed of the gases during the last tenth of the forward stroke, reckoned from their weight, as compared with the total weight of the products during exhaust. The speed depends on the mean speed of the engine.

Lastly, the total heat discharged from the beginning of exhaust to the admission of the fresh charge is reckoned, and the difference between it and the heat of the products remaining in the cylinder. It represents an energy transformed into—I. Energy of discharge; II. Back pressure negative work; III. Work of exhaust; and IV. Energy carried off in the water. The author concludes that, in the escaping gases and the products remaining in the cylinder, there is a certain amount of energy or work represented by their temperature. The difference between this temperature and that at the closing of the exhaust valve represents a loss of energy carried off during exhaust into the atmosphere, or to the walls. There is a perceptible increase in this heat parted with to the walls, with increase of speed in the engine.

SUMMARY OF APPENDIX F.

141 Tests of Gas, Oil, and Air Engines.

Table of 29 Tests of ENGLISH Gas Engines using LIGHTING Gas. See pages 476 to 479.

Diameter of cylinders . .	varying from	7 inches to 14 inches.
Strokes	,, ,,	9½ inches to 28 inches.
Revolutions per minute . .	,, ,,	130 to 253.
Indicated H.P. . . .	,, ,,	4 to 117.
Mechanical Efficiency . .	,, ,,	63 per cent. to 88 per cent.
Lighting Gas per B.H.P. hour	,, ,,	33 to 16½ cubic feet.
Heat Efficiency (taking B.H.P.)	,, ,,	12 per cent. to 27 per cent.

Table of 13 Tests of FRENCH Gas Engines using LIGHTING Gas. See pages 480 and 481.

Diameter of cylinders . .	varying from	5½ inches to 15 inches.
Strokes	,, ,,	11 inches to 23½ inches.
Revolutions per minute . .	,, ,,	143 to 180.
Indicated H.P. . . .	,, ,,	5 to 58.
Mechanical Efficiency . .	,, ,,	75 per cent. to 91 per cent.
Lighting Gas per B.H.P. hour	,, ,,	37 to 14½ cubic feet.
Heat Efficiency (taking B.H.P.)	,, ,,	20 per cent. to 22 per cent.

Table of 19 Tests of GERMAN Gas Engines using LIGHTING Gas. See pages 480 and 481.

Diameter of cylinders . .	varying from	5⅝ inches to 10½ inches.
Strokes	,, ,,	11 inches to 17¾ inches.
Revolutions per minute . .	,, ,,	119 to 204.
Indicated H.P.	,, ,,	3 to 7.
Mechanical Efficiency . .	,, ,,	65 per cent. to 90 per cent.
Lighting Gas per B.H.P. hour	,, ,,	45 to 18¼ cubic feet.
Heat Efficiency (taking B.H.P)	,, ,,	16 per cent.

Table of 19 Tests of GAS Engines—English, French, and German—using POWER Gas. See pages 482 and 483.

Diameter of cylinders . .	varying from	8 inches to 34 inches.
Strokes	,, ,,	14¼ inches to 39 inches.
Revolutions per minute . .	,, ,,	86 to 169.
Indicated H.P.	,, ,,	4 to 280.
Mechanical Efficiency . .	,, ,,	53 per cent. to 89 per cent.
Coal per B.H.P. hour . .	,, ,,	1 lb. to 2 lbs.

Table of 58 Tests of OIL Engines—English, French, and German. See pages 484 to 487.

Diameter of cylinders . .	varying from	5 inches to 12 inches.
Strokes	,, ,,	6·7 inches to 18 inches.
Revolutions per minute . .	,, ,,	160 to 325.
Brake H.P.	,, ,,	2 to 25.
Mechanical Efficiency . .	,, ,,	68 per cent. to 91 per cent.
Oil per B.H.P.	,, ,,	2¾ to 0·6 lbs.
Heat Efficiency (taking B.H.P.)	,, ,,	5 per cent. to 21 per cent.
Heating value of Oil per lb., T.U.	,, ,,	18,600 to 19,870.

Table of 3 Tests of AIR Engines. See pages 486 and 487.

Diameter of cylinders . .	varying from	13½ inches to 24 inches.
Strokes	,, ,,	7 inches to 16 inches.
Revolutions per minute . .	,, ,,	61 to 118.
Indicated H.P.	,, ,,	2⅓ to 20.
Mechanical Efficiency . .	,, ,,	55 per cent. to 71 per cent.
Fuel per B.H.P. hour . .	,, ,,	2½ lbs. to 7½ lbs.

SECTION F.—TABLE OF TRIALS AND TESTS OF

Name of Gas Engine.	Experiment made by	Place and Date of Test.	Dimensions of Engine.		Number of Revolutions per Minute.	Indicated H.P.
			Diameter of Cylinder.	Stroke.		
Various Old Engines.			Inches.	Inches.		
Original Lenoir,	Tresca	Paris, Jan., 1861	$7\frac{1}{10}$	4	130	...
,, ,,	,,	,, Mar., 1861	$9\frac{1}{2}$	$4\frac{3}{4}$	94	...
,, ,,	Clerk	London, Dec., 1885	$7\frac{1}{8}$	$11\frac{3}{4}$	85	1·17
Hugon,	Tresca	Paris, Feb., 1866	13	$12\frac{3}{4}$	53	3·55
Simon,	...	... ...	$9\frac{1}{4}$	$15\frac{1}{8}$	146	5·60
Beck,	Kennedy	London, Feb., 1888	7·5	15	206	7·25
Otto & Langen,	Tresca	Paris, Sept., 1867	$5\frac{9}{10}$	...	81	...
,,	Clerk	Oldham, Aug., 1884	12·5	40·5	...	2·90
Ajax,	Jamieson	Glasgow, Mar., 1889	8	15	173	10·04
Wittig & Hess,	Brauer & Schöttler	Altona, 1881	$7\frac{7}{8}$	$7\frac{1}{16}$	103	...
English Gas Engines—						
Otto-Crossley,	Garrett	Glasgow	9	16	154	14·26
,,	Brooks & Steward	Hoboken, U.S., 1884	8·5	14	158	9·60
,,	Adams	Crystal Palace, 1881	13	21	151	33·60
,,	,,	,, ,,	12	16	158	22·56
,,	,,	,, ,,	$5\frac{1}{4}$	12	160	3·42
,,	Soc. of Arts	London, Sept., 1888	9·5	18	160	17·12
,,	Capper	London, 1892	8·5	18	162	13·32
,,	Witz	Lille, Oct., 1893	13	20·8	163	43·00
Clerk,	Garrett	Glasgow, 1885	7	12	146	9·05
,,	,,	,, ,,	9	20	132	27·46
Atkinson (Differential),	Robinson	London	...	...	148	...
,, ,,	Schöttler	Magdeburg, 1886	...	...	159	...
Atkinson (Cycle)	Unwin	London, Apr., 1887	7·5	9·25	148	5·56
,, ,,	Society of Arts	,, Sept., 1888	9·5	12·43	131	11·15

GAS ENGINES USING *LIGHTING* GAS, 1861-1895.

Brake H.P.	Mechanical Efficiency per cent.*	Consumption of Gas. Per I.H.P. hour including ignition.	Consumption of Gas. Per B.H.P. hour including ignition.	British T.U. per hour. Per I.H.P.	British T.U. per hour. Per B.H.P.	Heat Efficiency per cent. (taking B.H.P.)	Authority, Reference, &c. The word "diagram" means that an indicator diagram is given in the text.
		Cubic feet.	Cubic feet.			Per cent.	
0·57	...	...	112	...	...	...	Witz, vol. i., p. 204.
0·90	...	...	96	...	...	0·04	,, ,,
...	...	73·50	...	45,862	...	0·05	Clerk, *Explosion of Gaseous Mixtures*, p. 45.
2·07	0·58	53·00	90·93	35,720	66,106	0·07	Witz, vol. i., p 204.
4·20	0·75	50·00	...	...	...	...	Richard.
6·31	0·87	21·68	27·67	13,267	16,917	0·15	Kennedy's Report, Diagram.
0·46	...	...	48·70	...	...	...	Witz, vol. i., p. 205.
2·00	0·69	28·60	42·00	...	...	...	Clerk, *Gas Engines*, p. 141.
8·84	0·87	18·90†	21·50†	15,336	17,479	...	Miller, *On Efficiencies*.
3·75	...	...	43·50	...	...	...	Schöttler, *Gas Maschine*, p. 146.
9·08	0·63	19·40	28·00	...	...	...	Clerk, *The Gas Engine*, p. 181.
8·10	0 84	24·50	29·10	15,118	17,957	0·17	Miller, *On Efficiencies*.
27·75	0·82	25·00	30·30	16,000	19,201	0·16	Inaugural Address to Society of Electricians, 1884.
18·31	0·81	23·60	29·10	15,080	18,594	0·17	
2·87	0·84	30·90	33·40	19,745	21,342	0·14	
14·74	0·86	20·76	24·10	12,120	14,093	0·21	Report of Trial, Diagram.
11·33	0·85	20·87	25·22	13,141	15,880	0·22	See Appendix, full details and diagram.
38·05	0·88	19·00	21·50	10,849	12,276	0·21	Witz, vol. ii., p. 168.
7·23	0·80	24·30	30·42	19,756	24,731	0·12	Clerk, *Gas Engine*, p. 191, Diagram.
23·21	0 84	20·39	24·12	16,495	19,609	0·15	,, ,,
2·60	...	...	25·77	...	...	...	Robinson, p. 45.
2·22	...	...	30·50	...	...	...	Schöttler, p. 168, Diagram.
4·89	0·88	19·78	22·50	11,704	13,596	0·22	Report of Trial, Diagram.
9·48	0·85	19·22	22·61	11,250	13,507	0·22	,, ,,

$* = \frac{\text{B.H.P.}}{\text{I.H.P.}}$ † Excluding ignition.

TABLE OF TRIALS AND TESTS OF GAS

Name of Gas Engine.	Experiment made by	Place and Date of Test.	Dimensions of Engine. Diameter of Cylinder.	Stroke.	Number of Revolutions per Minute.	Indicated H.P.
ENGLISH ENGINES —*Contd.*			Inches.	Inches.		
Griffin,	Society of Arts	London, Sept., 1888	9·2	14	198	15·47
,,	Prof. Kennedy	Kilmarnock, 1888	9	14	224	17·46
,,	Prof. Jamieson	,, Nov., 1887	9	14	183	17·28
,,	,,	Glasgow, Dec., 1891	13	20	157	63·00
,,	Prof. Kennedy	Kilmarnock, Sept., 1894	13·5	20	158	117·00
Bisschop,	Meidinger	... ...	...	...	81	...
Fawcett,	Miller	Liverpool, Feb., 1890	8	16	151	11·49
Acmé,	Rowden	Glasgow, Dec., 1890	...	...	170	...
Forward,	Robert Smith	Birmingham, May, 1888	7	15·1	177	5·54
,,	Morrison	Birmingham, Jan., 1894	12	20	170	27·15
Trusty,	*The Engineer*	Crystal Palace, June, 1892	7·5	14	201	11·90
Premier,	Goodman	Yorkshire Coll., Leeds, June, 1895	14	28	153	63·80
,,	,,	Yorkshire Coll., Leeds, June, 1895	8·2	15	253	17·60
Tangye,	Witz	Roubaix, Jan., 1895	11·5	18	172	36·64
Crossley-Atkinson,	Atkinson	Openshaw, 1894	11½	21	173	46·45
,, ,,	D. Clerk	,, Aug., 1894	7	15	200	14·00

ENGINES USING *LIGHTING* GAS—*Continued.*

Brake H.P.	Mechanical Efficiency per cent.	Consumption of Gas. Per I.H.P. hour including ignition.	Per B.H.P. hour including ignition.	British T.U. per hour. Per I.H.P.	Per B.H.P.	Heat Efficiency per cent. (taking B.H.P.) *	Authority, Reference, &c. The word "diagram" means that an indicator diagram is given in the text of this Book.
		Cubic feet.	Cubic feet.			Per cent.	
12·51	0·80	23·10	28·56	13,380	16,538	0·19	Report of Trial, Diagram
14·94	0·85	18·92	23·58	12,089	15,067	0·21	,, and Miller
13·60	0·78	19·27	24·48	12,313	15,642	0·20	,, ,,
51·00	0·81	14·00	17·00	...	...	...	,,
...	0·76	17·30	23·60	...	...	...	,,
0·45	...	...	74·00	...	...	...	Schöttler, p. 30.
8·52	0·74	18·40†	24·74†	13,082	17,590	0·19	Miller, *On Efficiencies.*
8·28	...	...	17·30	...	14,064	...	Report of Trial.
4·80	0·86	20·79†	23·99†	13,284	15,316	...	,, Diagram.
22·85	0·84	23·00	26·30	14,812	16,937	0·18	*Engineer*, April 6, 1894.
7·90	0·66	15·95	24·00	...	...	0·18	*Engineer*, June 3, 1892.
...	...	15·27	...	9,420	...	0·28 I.H.P.	Report of Trial.
13·50	0·76	16·30	21·25	10,187	13,281	0·20	,,
31·00	0·85	16·00	18·90	...	...	...	,,
39·91	0·86	14·50	16·48	9,280	10,547	0·24	Manchester Assoc. Engineers, 1894 (Long Exhaust Pipe).
12·00	0·86	14·80	17·00	...	...	0·27	P.I.C.E., Clerk, Paper on Gas Engine, 1896 (Long Exhaust Pipe).

* Heat efficiency = percentage heat in B.H.P. of total heat in the oil used. † Excluding ignition.

TABLE OF TRIALS AND TESTS—*Continued.*

Name of Gas Engine.	Experiment made by	Place and Date of Test.	Dimensions of Engine.		Number of Revolutions per Minute.	Indicated H.P. (French).*
			Diameter of Cylinder.	Stroke.		
French Gas Engines.			Inches.	Inches.		
Simplex.	Witz	Rouen, Nov., 1885	7⅞	15·75	161	9·10
Second Lenoir,	Tresca	Paris, May, 1885	5·5	11·0	176	...
"	Hirsch	" " 1890	9	15·75	160	...
Niel,	Moreau	" Jan., 1891	7	14·0	160	5·26
"	...	Evreux, June, 1891	5 11/16	11⅜	180	...
Ravel,	Monnier	Paris, April, 1889	7·10	14·20	161	9·31
Charon,	Witz	Solre-le-Château, April, 1889	7·10	14·20	166	...
"	Chauveau	Paris, May, 1891	8·2	15·75	160	...
"	Modelski and Coustolle	Bassin de la Pallice, June, 1892	11	17·75	143	28·80
"	Costa	Marseille, Apr., 1894	9 1/16	16½	160	...
"	Allaire & Cuinat	Solre-le-Château, April, 1894	13·75	23·6	150	58·3
"	Witz	Solre-le-Château, March, 1895	15	23·6	153	...
"	"	Solre-le-Château, Feb., 1895	7·3	14·0	161	...
German Gas Engines.						
Koerting-Lieckfeldt,	Schöttler	... ...	7·10	14·20	119	not given
Koerting,	Fischer	Hanover, Dec., 1890	not given	not given	151	"
"	Müller	Feb., 1889	"	"	204	"
"	Epstein	Frankfort, Oct., 1893	"	"	...	"
Benz,	...	Carlsruhe, 1886	"	"	152	"
Adam,	Richard	" "	"	"	167	"
"	Aeppli	Winterthur, 1889	"	"	180	"
"	Schröter	Munich, Jan., 1886	"	"	173	"
Lützky,	Schöttler	Harburg, 1891	"	"	200	"
Hille,	Lewicki	Dresden, June, 1891	"	"	153	7·20
"	Schöttler	" Feb., 1892	10·6	17·7	137	...
Deutz-Otto,	Brauer & Slaby	Berlin, Mar., 1878	5·5	11·0	180	3·20
"	Brauer & Slaby	Erfurt, Aug., 1878	6·7	13·5	160	6·03
"	Slaby	Deutz., Aug., 1881	6·7	13·5	157	5·04
"	Brauer & Schöttler	Altona, Sept., 1881	not given	not given	159	...
"	Meidinger	Karlsruhe, 1882	"	"	159	...
"	Allard & Tresca	Paris, 1881	6·7	13·4	155	5·26
"	Witz	Roubaix, 1883	6·7	13·4	160	...
"	Teichmann	Stuttgardt, April, 1892	...	...	181	...

* French H.P. = 0·98 English H.P.

FRENCH AND GERMAN ENGINES USING *LIGHTING* GAS, 1885-1895.

Brake H.P. (French).	Mechanical Efficiency per cent.	Consumption of Gas. Per I.H.P. hour including ignition.	Consumption of Gas. Per B.H.P hour including ignition.	British T.U. per hour. Per I.H.P.	British T.U. per hour. Per B.H.P.	Heat efficiency per cent. (taking B.H.P.	Authority, Reference, &c. The word "diagram" means that an indicator diagram is given in the text.
		Cubic feet.	Cubic feet.			Per cent.	
8·79	...	...	20·38	...	13,338	0·20	Witz, Report.
1·93	...	...	23·19	...	14,887	...	Report of Trial, Diagram.
16·13	...	...	21·20	...	12,804	0·20	,, Witz, vol. i., p. 219
4·00	0·75	...	27·20	...	17,460	...	*Comptes Rendus*, Oct., 1891, Diagram.
3·15	...	...	14·20	...	...	...	Witz, vol. i., p. 221.
7·01	0·75	28·4	37·70	...	...	...	,, p. 218.
4·18	...	...	18·60	...	12,462	...	,, ,,
7·48	...	..	20·70	...	...	...	Witz, vol. ii., p. 159.
24·93	0·86	...	16·46	...	...	...	,, p. 166.
20·09	...	...	17·00	...	...	...	,, p. 170.
53·15	0·91	. .	16·90	...	...	...	,, p. 203 & Report
60·42	...	...	16·00	...	9,568	0·22	Report of Trial.
4·71	...	...	16·80	...	10,382	...	,,
2·18	...	...	45·0	...	...	not given	Witz, vol i., p. 208.
20·13	...	...	23·8	...	...	,,	Report of Trial.
5·55	...	...	30 0	...	...	,,	,,
39·80	...	...	18·2	..	10,374	,,	,,
5·61	...	...	25·0	...	...	,,	Schöttler, p. 159.
4·47	...	...	31·0	...	...	,,	Report of Trial.
2·46	...	...	33·0	...	...	,,	,,
11·16	...	...	31·6	...	...	,,	,,
6·29	...	...	24·0	...	...	,,	*Vereines d. Ingenieure*, Aug. 22, 1891.
6·82	0·90	...	26·0	...	...	,,	Report of Trial.
16·54	...	...	24·0	...	...	,,	,,
2·08	0·65	...	40·2	...	...	,,	Witz, vol. i., p. 206.
3·98	0·66	...	38·0	...	...	,,	,, ,,
4·4	0·87	28·3	32·4	15,536	17,810	0·16	Jenkin, *Gas and Caloric Engines*, Diagram.
3·96	...	...	32·0	...	...	not given	Schöttler, p. 87, & Witz
4·11	...	...	33·0	...	...	,,	,, p. 86.
3·94	0·74	...	31·0	...	16,957	,,	Witz, Vol. i., p. 209.
3·70	0·85	...	39·0	...	...	,,	,, ,, p. 210.
10·09	...	...	23·6	...	...	,,	*Zeit. d. V. d. Ing.*, Dec. 16, 1893.

TABLE OF TRIALS AND TESTS OF *GAS* ENGINES USING

Name of Gas Engine.	Generator used.	Experiment made by	Place and Date.	Dimensions of Engine. Diameter of Cylinder.	Stroke.	Number of Revolutions per Minute.
				Inches.	Inches.	
Otto, . .	Dowson	D. K. Clark	1881	...	...	156
Deutz-Otto, .	,,	Teichmann and Böcking	Deutz, 1887	13·4	...	140
,, ,, .	,,	Beck	Nuremberg, 1888	...	...	...
,, ,, .	,,	Monaco	Canale, Italy, Jan., 1890	...	...	140
,, ,, .	,,	Meyer	Zurich, June, 1895	16·9	23·9	169
Crossley-Otto,	,,	Crossley	Dec., 1892	13·0	18	...
,, ,,	,,	Severn Tweed Co.	Dec., 1891	...	...	...
,, ,,	,,	Dowson	Chelsea, Feb., 1892	17 0	24	155
,, ,,	,,	Witz	Sabadell, June, 1894	17·0	23	164
,, ,,	,,	Cavailles	Montolieu, Dec., 1893	11·5	16	164
Atkinson (cycle),	,,	Tomlinson	Uxbridge, Oct., 1891	14·0	14·3	86
Stockport, .	,,	Robb	Portadown, May, 1895	...	...	152
Simplex, .	,,	Witz	Lille, Nov., 1885	7·8	15·75	164
,, .	,,	,,	Sept., 1890	22·6	38	101
,, .	Lencauchez	Bourdon	Étrepagny, Mar., 1894	18·9	27	140
,, .	,,	Leneveu	Aubervilliers, Nov., 1894	23·0	30	120
,, .	,,	...	Pantin, Feb., 1894	34·0	39	100
Schleicher-Schumm Otto,	Taylor	Spangler	U. States, May, 1892	14·5	25	160
Bénier. . .	Bénier	Witz	Paris, Nov., 1894	11·8	17·3	151

POWER GAS, 1881-1895.—*ENGLISH, FRENCH, AND GERMAN.*

Indicated H.P. (French).	Brake H.P. (French).	Mechanical Efficiency per cent.	Consumption of Coal. Per I.H.P. per Hour.	Consumption of Coal. Per B.H.P. per Hour.	Kind of Coal used in Generator.	Authority, Reference Date, &c. The word "diagram" in this column means that an indicator diagram of the trial is given in the text.
			Lbs.	Lbs.		
4·41	3·26	0·74	1·45	1·97	Anthracite	Dowson, *Cheap Gas*, *Proc. Inst. C. E.*, vol. lxxiii.
...	50·80	...	...	1·70	Not given	Schöttler, p. 102.
...	30·00	...	...	1·97	,,	Dowson, *Gas Power*.
...	35·95	...	...	1·90	,,	,, ,,
51·10	40·90	0·80	1·10	1·40	Belgium anthracite	*Zeit. d. V. deutscher Ing.*, Dec., 1895.
27·50	...	...	1·40	...	Anthracite	Dowson, *Cheap Gas*.
...	96·03	...	...	1·23	,,	*Journ. Gas Lighting*, Jan. 5, 1892.
118·70	...	...	0·76	...	,,	*The Engineer*, Feb. 12, 1892, Diagram.
77·46	60·18	0·78	1·24	1·60	,,	Witz, vol. ii., p. 171.
20·16	15·22	0·75	1·40	1·80	French coal	,, ,, p. 169.
21·90	..	...	1·06	...	Anthracite	*The Engineer*, Feb. 12, 1892, Diagram.
44·60	...	...	0·89	...	,,	Report of Trial.
8·10	7·22	0·89	...	1·33	Not given	Witz, vol. i., p. 215.
110·00	75·86	0·69	...	1·34	Anthracite	,, ,, p. 220, Diagram.
...	62·55	...	...	1·30	French coal, Anzin	,, vol. ii., p. 170.
105·80	81·40	0·77	1·10	1·45	,,	Report of Trial.
280·00	220·00	0·78	0·80	1·02	,,	,, ,,
127·60	92·50	0·72	0·94	1·30	Not given	*Journ. Franklin Institute*, May, 1893.
27·60	14·59	0·53	...	1·50	,,	Report of Trial.

TABLE OF TRIALS AND TESTS OF *OIL*

Name of Oil Engine.	Specific Gravity Oil used.	Experiment made by	Place and Date.	Dimensions of Engine. Diameter of Cyl.	Stroke.	Number of Revolutions per Minute.	Indicated H.P.
				Inches.	Inches.		
Brayton, . .	0·85	Dugald Clerk	Glasgow, Feb., 1878	8·0	12	201	5·39
Priestman, .	0·79	Unwin	Plymouth, 1889	8·5	[illegible]	204	9·36
" . .	...	"	Hull, 1891	...	...	207	7·40
" . .	0·81	"	Plymouth, 1890	8·5	12	180	5·24
" . .	...	Douglass	" 1891	...	...	...	...
Hornsby, . .	0·85	Robinson	...	8·25	14	224	6·74
" . .	0·82	Ringelmann	Meaux, May, 1894	8·0	14·1	205	...
" . .	...	Capper	Cambridge, June, 1894	12·0	16	196	16·1
" . .	...	"	" "	10·0	15	240	10·3
Trusty, . .	0·81	Beaumont	Guildford	7·75	14	230	6·2
" . .	...	Capper	Cambridge, "	6·75	13	260	6·5
" . .	...	Beaumont	Guildford, May, 1893	7·37	14	248	7·0
Crossley-Otto, .	...	Capper	Cambridge, June, 1894	7·0	15	201	7·9
" " .	...	"	" "	8·5	18	206	14·5
Campbell, .	...	"	" "	7·5	12	207	5·9
" .	...	"	" "	8·5	16	180	11·0
Premier, . .	...	"	" "	8·25	15	160	7·3
Roots, . .	...	"	" "	7·50	13	240	8·4
Lenoir, . .	...	Tresca	Paris, 1885	...	...	159	Not indicated.
Durand, . .	0·60	...	...	...	...	180	
Forest, . .	...	Martin	Brest, 1890	6·3	13·4	166	
Niel, . .	...	Ringelmann	Meaux, May, 1894	7·17	14·17	183	
Griffin, . .	...	"	" "	6·0	12·0	218	
Niel, . .	...	"	" "	7·17	14·17	177	
Merlin, . .	...	"	" "	6·7	6·7	283	
Robey, . .	...	Schöttler & Hartmann	Berlin, June, 1894	6·0	9·0	300	
Deutz-Otto, .	0·82	Otto	Deutz	...	...	212	
" " .	...	Meyer	Zurich, Oct., 1894	6·6	10·2	210	
" " .	...	Schöttler & Hartmann	Berlin, June, 1894	6·1	9·4	229	
Altmann, . .	...	" "	" "	9·0	15·7	209	
Lüde-Langensiepen,	0·82	Schöttler	Magdeburg, 1891	7·1	7·9	325	
Langensiepen, .	0·80 to 0·82.	Schöttler & Hartmann	Berlin, June, 1894	8·6	7·8	304	
Deutz-Otto, .		" "	" "	7·8	9·4	297	
Grob-Capitaine,		" "	" "	9·0	9·0	252	
" "		" "	" "	7·28	7·28	290	
" "		Ringelmann	Meaux, May, 1894	7·4	7·4	263	
" "		"	" "	7·4	7·4	311	
" "		...	Leipzig, May, 1893	[illegible]	9·0	278	12·9

ENGINES, 1878-1895.—*ENGLISH, FRENCH, AND GERMAN.*

Brake H.P.	Mechanical Efficiency per cent.	Consumption of Oil per Hour. Per I.H.P.	Per B.H.P.	British T.U. per Hour. Per I.H.P.	Per B.H.P.	Heat Efficiency per cent. (taking B.H.P.)	Authority, Date, Oil used, and its Heating Value, &c.
		Lbs.	Lbs.				
4·26	0·79	2·16	2·72	23,760	29,920	0·06 I.H.P.	Clerk, *The Gas Engine*, p. 159.
7·72	0·82	0·69	0·84	13,670	16,580	0·15	*Inst. Civil Engin.*, vol. cix., 1891.
6·76	0·91	0·86	0·94	...	...	...	,, 19,000 T.U. per lb.
4·49	0·85	1·06	1·24	20,140	23,560	0·10	,, Broxburn oil; 19,700 T.U. per lb.
25·50	...	...	0·88	...	...	...	,, ,, ,,
...	...	0·90	...	...	...	...	*Engineering*, Oct. 9, 1891.
5·71	...	...	1·20	...	23,760	0·10	Report of Meaux Trials; 19,870 T.U. per lb.
11·19	0·69	0·75	1·08	13,950	20,082	...	*Journ Royal Agri. Soc.*, 1894.
8·57	0·83	0·81	0·97	15,066	18,042	0·14	,, ,, Russoline oil.
4·28	0·68	0·66	0·96	...	...	...	*The Engineer*, Dec. 4, 1891; Broxburn oil used.
4·73	0·73	0·87	1 19	16,182	22,134	...	*Journal of R. Agri. Society*, 1894.
5·98	0·85	0·69	0·82	13,572	15,990	0·16	Report of Trial; Royal Daylight Oil.
7·01	0·88	0·73	0·82	13,578	15,250	0·16	*Journ. Royal Agri. Soc.* — Russoline oil used. 18,600 T.U. per lb.
9·99	0·69	0·62	0·98	11,532	18,228	Heat efficiency is the percentage of heat turned into B.H.P. of total heat in the oil used.	,, 1894. ,,
4·81	0·80	0·93	1·12	17,298	20,832		,, ,,
9·61	0·87	0·99	1·72	18,414	31,992		,, ,,
6·46	0·89	0·93	1·04	17,298	19,344		,, ,,
6·21	0·74	1·25	1·68	23,250	31,248		,, ,,
4·15	Not indicated.	Not indicated.	0·92	Not indicated.	...		Witz, vol. i., p. 215.
2·88			0·93		...		,, ,, p. 216.
16·67			1·00		...		,, ,, p. 219.
6·23			0·67		13,266	0·18	Report of Meaux Trials; Russian oil used.
7·38			0·93		18,414	0·13	Report of Meaux Trials; Russian oil used; 19,870 T.U. per lb.
6·38			1·54		30,498	0·08	,, ,, ,,
4·80			0·76		15,048	0·16	See *Proc. Inst. C. E.* for summary of these trials, vol. cxxi., 1894-5.
1·82			2·61		50,843	0·05	Report, Hartmann.
5·30			0·88		...	...	*Inst. C. E.*, vol. cix., Diagram.
4·52			0·89		17,544	...	*Zeit. d. V. deut. Ing.*, Aug. 17, 1895.
4·00			1·26		24,545	0·10	Report, Hartmann. — T.U. per lb., see below.
8·16			0·83		16,168	0·15	,, ,,
6·70			0·83		...	...	*Zeit. d. V. deut. Ing.*, Aug. 29, 1891.
7·33			1·05		20,454	0·12	Report, Hartmann. — American or Russian oil; 19,480 T.U. per lb.
9·19			0·96		18,700	0·15	,, ,,
7·12			1·21		23,571	0·10	,, ,,
3·88			1·16		22,597	0·11	,, ,,
6·20			0·92		18,216	0·13	Report of Meaux Trials. — Russian oil; T.U. per lb., see above.
7·34			0·59		11,682	0·21	,, ,,
10·50	0·81	0·86	1·07	...	...	...	*Zeit. d. V. deut. Ing.*, Feb. 24, 1894.

TABLE OF TRIALS AND TESTS OF *OIL* ENGINES,

Name of Oil Engine.	Specific Gravity Oil used.	Experiment made by	Place and Date.		Dimensions of Engine.		Number of Revolutions per Minute.	Indicated H.P.
					Diameter of Cyl.	Stroke.		
					Inches.	Inches.		
Winterthur Soc.,	0·80 to 0·82.	Ringelmann	Meaux,	May, 1894	6·3	9·4	226	Not indicated.
Altmann, . .		Schöttler & Hartmann	Berlin,	June, 1894	11·0	15·7	209	
Langensiepen, .		,, ,,	,,	,,	8·6	10·0	271	
Seck, . .		,, ,,	,,	,,	7·5	7·5	300	
,, . .		,, ,,	,,	,,	7·5	7·5	302	
Hille, . .		,, ,,	,,	,,	7·8	15·7	244	
,, . .		,, ,,	,,	,,	5·1	9·0	250	
Dürkopp, . .		,, ,,	,,	,,	8·6	13·3	211	
,, . .		,, ,,	,,	,,	6·9	11·0	224	
Daimler, . .		,, ,,	,,	,,	6·8	11·0	221	
,, . .		,, ,,	,,	,,	6·9	11·0	220	
Swiderski-Capitaine,		,, ,,	,,	,,	6·6	7·0	315	
,, ,,		,, ,,	,,	,,	9·8	9·8	249	
Schwartzkopff, .		,, ,,	,,	,,	9·8	15·7	193	
					6·6	11·8	234	

TABLE OF *AIR*

Air Engine.	Experiment made by	Place and Date.	Dimensions of Engine.		Duration of Test.	No. of Revolutions.
			Diam. of Cyl.	Stroke.		
Buckett, ...	Ingrey	Caloric Co.	24 in.	16 in.	...	61
Bailey, ...	...	—	14⅜ ,,	6¼ ,,	..	106
Bénier.	Slaby	Cologne, 1887	13·4 ,,	13·8 ,,	2½ hrs.	117·6

1878-1895.—*ENGLISH, FRENCH, AND GERMAN.*—*Continued.*

Brake H.P.	Mechanical Efficiency per cent.	Consumption of Oil per Hour.		British T.U. per Hour.		Heat Efficiency per cent. (taking B.H.P.)	Authority, Date, Oil used, and its Heating Value, &c.
		Per I.H.P.	Per B.H.P.	Per I.H.P.	Per B.H.P.		
		Lbs.	Lbs.				
5·21	Not indicated.	Not indicated.	0·84	Not indicated.	[illegible]	0·14	Report of Meaux Trials; Russian oil.
12·10			0·93		18,116	0·12	Report, Hartmann. 19,480 T.U. per lb.
7·82			1·13		22,012	0·11	,, ,,
4·40			[illegible]		19,870	0·12	Report of Prof. Hartmann. Oil used, American or Russoline, of heating value 19,380 T.U. to 19,580 T.U. per lb.
4·23			0·96		18,700	0·14	,, ,,
10·56			1·10		21,028	0·11	,, ,,
3·12			0·99		19,285	0·10	,, ,,
8·50			1·00		19,480	0·12	,, ,,
4·46			[illegible]		24,934	0·10	,, ,,
3·71			1·25		24,350	0·13	,, ,,
3·25			[illegible]		[illegible]	0·09	,, ,,
3·96			0·96		18,700	0·13	,, ,,
10·00			0·82		15,974	0·13	See *Proc. Inst. C. E.* for summary of these trials, vol. cxxi., 1894-95.
[illegible]			1·01		19,675	0·13	,, ,, ,,
[illegible]			1·16		22,597	0·12	,, ,, ,,
4·15			[illegible]		25,714	[illegible]	,, ,, ,,
2·38			1·47		28,636	0·10	,, ,, ,,
4·13			1·23		23,960	0·10	,, ,, ,,
9·80			1·30		25,324	0·10	,, ,, ,,
6·82	0·80	0·88	1·10	16,368	20,460	0·12	B. Donkin's test. Russoline oil, [illegible]

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20·2	14·39	1·8 lbs	2·54 lbs.	0·71	Jenkin, *Gas and Caloric Engines*, *Inst. C. E.*, 1883.
2·37	1·31	4·2 ,,	7·6 ,,	0·55	,, ,, ,, ,,
5·85	[illegible]	3·1 ,,	3·6 ,,	0·69	*Zeits. Ver. deutscher Ing.*, vol. xxxiii., p. 59.

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INDEX.

A

B

V

W

Y

Z

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